



## REVIEW AND RECOMMENDATIONS FOR MINIMUM LIVESTOCK MANURE NITROGEN EFFICIENCY COEFFICIENTS

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## EXECUTIVE SUMMARY

A key element of the Nitrate Vulnerable Zones-Action Programme (NVZ-AP) in England and Wales is the requirement for farmers to formally take into account the crop available nitrogen (N) supply from livestock manure applications. Minimum manure N efficiency coefficients have been set, which farmers must use when calculating how much of the total N content of livestock manures applied to their land is available for the next crop grown. The European Commission view the manure N efficiency coefficients as a key factor in driving improvements in manure management practices, leading to greater on-farm N use efficiency.

In this study, manure N efficiency coefficients in other Atlantic European countries, where agro-climatic conditions are comparable to those in Britain (i.e. The Netherlands, Flanders (Belgium), Denmark, Germany, France, Northern Ireland and Eire) were reviewed. This confirmed that manure N efficiency coefficients in the England (Scotland and Wales) NVZ-APs were generally at the lower end of the range of values for all manure types.

The existing evidence base for England (and Wales) was reviewed and a methodology developed to assess whether higher manure N efficiency coefficients could be achieved. Based on our review of field experimental data and manure N efficiency recommendations in Defra's "Fertiliser Manual (RB209)", which were produced using the MANNER-NPK software and validated against measured field experimental data, we consider that some increases in N efficiency coefficients can be justified in the next (2013-16) NVZ-AP, as summarised below:

Manure type	Present NVZ-AP (from 1 <sup>st</sup> January 2012)	<i>Suggested values in next NVZ-AP</i>
Cattle slurry	35	40
Pig slurry	45	50/55
Poultry manures	30	35
FYM	10	10/15

These values may seem ambitious, however, where manures are applied regularly there is good evidence to show that previous manure applications will supply N to following crops through the mineralisation of organic N. Also, there are improvements that can be made in slurry management practices to improve N use efficiency e.g. through the use of band spreading/shallow injection equipment, slurry separation etc.

To assist farmers in achieving these higher N efficiencies, it will be necessary to 'encourage' improvements in manure management and spreading practices through a combination of increased investment in farm (manure management) facilities and advice provision.

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## 1. INTRODUCTION

A key element of the Nitrate Vulnerable Zones-Action Programme (NVZ-AP) in England (SI, 2008) and Wales (WSI, 2008) is the requirement for farmers to formally take into account the crop available nitrogen (N) supply from livestock manure applications, including the use of minimum manure N efficiency coefficients (sometimes also referred to as manure N fertiliser replacement values). These represent the amount of N in livestock manure which has the same effectiveness as manufactured N fertiliser i.e. the ratio of the effect of one kg of manure N on crop dry matter yield to the effect of one kg of manufactured fertiliser N on crop dry matter yield (Schroder *et al.*, 2007).

Standard manure N efficiency coefficients (expressed as a percentage of the total N content) for livestock manures have been set for Britain (Table 1). Farmers must use these percentages when calculating how much of the total nitrogen content for livestock manures applied to their land is available for crop uptake in the season following application (i.e. efficiency to the next crop grown).

**Table 1: Minimum livestock manure N efficiency coefficients from the current NVZ-AP in Britain (SI, 2008; WSI, 2008; SSI, 2008)**

Manure type	Crop available N (% of total N applied) from 1 <sup>st</sup> January 2009	Crop available N (% of total N applied) from 1 <sup>st</sup> January 2012
Cattle slurry	20	35
Pig slurry	25	45
Poultry manures	20	30
Other livestock manures	10	10

A key aim of the NVZ-AP is to maximise the efficiency of livestock manure N use. Applications in the autumn (and early winter) can result in a small percentage of the total N applied being taken up by the crop. For example, an autumn (August to October) application of 6% dry matter cattle slurry surface applied on a sandy soil, can result in as little as 5% of the total N being available to the next crop grown. In comparison, 35% of the total N can be available if the same application was made in the spring (Defra, 2010). Moreover, slurry application using a band spreader (e.g. trailing hose/shoe) will further increase the spring N efficiency by 5%. There is therefore a clear environmental and financial benefit in making more efficient use of the crop available N supplied by livestock manure applications.

During negotiations with the European Commission on the present NVZ-AP (2009-2012), a particularly contentious issue was at what level minimum manure N efficiency coefficients should be set. The Commission wanted higher percentages similar to those established in some other Member States, and for a wider range of organic manure types. The Commission see these

figures as a key factor in driving improvements in nutrient management practices that will lead to greater on-farm N use efficiency. The European Commission only agreed to the English (British) 'position' on minimum livestock manure N efficiency coefficients, as enshrined in the Nitrate Pollution and Prevention Regulations (SI, 2008; WSI, 2008; SSI, 2008), on the condition that further research was undertaken to determine if higher manure N efficiency coefficients could be included in next NVZ-AP (2013-2016).

## 2. OBJECTIVES

The objectives of this study were to:

1. Review the manure N efficiency coefficients established in other Member States and how Member States have supported farmers to adjust their management practices to achieve these.
2. Review the existing evidence base for England (and Wales) and develop a robust methodology for identifying manure N efficiency coefficients that are achievable for different livestock manure types, under different environmental conditions and manure management practices.
3. Consider the environmental impacts of revised manure N efficiency coefficients for potential adoption in the next NVZ-AP.
4. Identify what manure management practices will be necessary to achieve different manure N efficiency coefficients and what actions Government could take to support achievement of these.
5. Identify gaps in information and the need for further field-based or other research. Provide recommendations for further R&D.
6. Provide clear recommendations for minimum manure N efficiency coefficients of different livestock manures for potential adoption in the next NVZ-AP. The recommendations will be supported by robust evidence and clear arguments that can be presented to the Commission and stakeholders.

### **3. MANURE NITROGEN EFFICIENCY COEFFICIENTS AND SUPPORT IN OTHER MEMBER STATES**

#### **3.1 Review of manure N efficiency coefficients**

In this study, manure N efficiency coefficients that have been established in other Atlantic European countries, where agro-climatic conditions are comparable to those in Britain, were reviewed. A recent review of agricultural N use in selected EU countries for the Dutch Ministry of Agriculture, Nature and Food Safety (van Dijk and ten Berge, 2009), included a comparison of manure N efficiency coefficients in the APs of The Netherlands, Flanders (Belgium), Denmark, Germany and France, which are summarised in Table 1. Data from the Northern Ireland and Eire (Southern Ireland) APs have also been included in Table 2.

The manure N efficiency coefficients in the Danish AP were the highest of all the countries reviewed, whilst those in the British (i.e. England, Wales and Scotland) NVZ-APs were generally at the lower end of the range of values for all manure types. Notably, France does not specify manure N efficiency coefficients in its AP. Also, the Flemish AP does not explicitly specify manure N efficiency coefficients, but uses values to underpin maximum allowable N application rates (van Dijk and ten Berge, 2009).

van Dijk and ten Berge (2009) noted that manure N efficiency coefficients used in Member State APs do not always agree with the values published in the Member State's advisory system recommendations. This was most apparent for slurries (applied to winter wheat and grassland) and for solid cattle manure, where the values in the Dutch, Flemish and Danish APs were higher than those recommended in their advisory systems.

The range of manure types for which manure N efficiency coefficients were specified varied depending on the agricultural and manure management practices within a country. For example, the Dutch and Danish APs specify manure N efficiency coefficients for separated slurries (liquid and solid fractions), reflecting the uptake of slurry separation technologies. In Eire and The Netherlands, manure N efficiency coefficients for spent mushroom compost are specified reflecting the importance of this industry in these countries. Also, different countries use different terminologies, especially in relation to 'solid manures', and it is not always possible to determine if these refer to equivalent manure types to those applied to land in Britain. Moreover, manure management practices (e.g. the type and rate of bedding material used) may differ such that a 'solid manure' in one country may have a very different composition and N content to that in another Member State.

**Table 2: Manure N efficiency coefficients in the NVZ-APs of selected Atlantic EU countries**

Manure type	Great Britain <sup>1</sup>		Northern Ireland <sup>2</sup>			Eire <sup>3</sup>			Denmark <sup>4</sup>	Flanders <sup>4</sup>	Germany <sup>4</sup>	Netherlands <sup>5</sup>
	From 1/1/09	From 1/1/12	From 1/1/07	From 1/1/09	From 1/1/10	From 1/1/07	From 1/1/08	From 1/1/10				2010-13
Cattle slurry	20	35	30	35	40	30	35	40	70	60	50	60 <sup>6</sup>
Cattle slurry and solid manure (grassland farms with mixed grazing/cutting)	-	-	-	-	-	-	-	-	-	-	-	45
Solid cattle manure	-	-	-	-	-	-	-	-	65	30	25	-
Pig slurry	25	45	35	45	50	35	40	50	75	60	60	60/70 <sup>7</sup>
Solid pig manure	-	-	-	-	-	-	-	-	-	-	-	55 <sup>8</sup>
Poultry manure/litter	20	30	20	24	30	35	40	50	65	30	30	55
Farmyard manure	10	10	20	25	30	20	25	30	-	-	-	-
Other livestock manures	10	10	-	-	-	30	35	40	-	-	-	40
Liquid fraction after separation	-	-	30	35	40	-	-	-	85	-	90	80
Solid fraction after separation (cattle)	-	-	-	-	-	-	-	-	65	-	-	-
Solid fraction after separation (pigs)	-	-	-	-	-	-	-	-	65	-	-	-
Dirty water	-	-	30	35	40	-	-	-	-	-	-	-
Spent mushroom compost	-	-	-	-	-	35	40	45	-	-	-	25
Other organic fertilisers	-	-	-	-	-	-	-	-	-	-	-	50

<sup>1</sup>Source: SI (2008)

<sup>2</sup>Source: DARDNI/EHSNI (2007)

<sup>3</sup>Source: SI (2009)

<sup>4</sup>Source: van Dijk and ten Berge (2009)

<sup>5</sup>Source: MINLNV (2010). 4<sup>th</sup> Action Programme

<sup>6</sup>Only used on farms with zero grazing. Cattle slurry and solid manure

<sup>7</sup>60% on clay and peat soils; 70% on sandy and loess soils

<sup>8</sup>Also includes solid manure from mink



For some countries, more detailed information was available on the reasoning behind the values that were specified in their respective NVZ-APs, viz.:

**Denmark.** van Dijk and ten Berge (2009) reported that the Danish manure N efficiency coefficients (DLBR, 2007) were derived from:

- Trials with animal manure at the Danish Agricultural Advisory Centre since the mid 1980s, and at the State Research Centre (Foulum) and;
- Trials determining ammonia emissions at the State Research Centre (Foulum).

Manure N efficiency coefficients were stated for pig slurry, cattle slurry, degassed slurry, separated slurry liquid and solids, solid cattle manure, deep litter from cattle, pigs, horses and sheep, and poultry manure. Values were also stated for different application timings (spring, summer, autumn and winter), slurry application techniques (injection and trailing hose) and crops (spring sown cereals, beets and maize, winter cereals, winter oilseed rape, grass for seed, grass for cutting/grazing).

For slurries, the AP manure N efficiency coefficients (70% for cattle slurry and 75% for pig slurry) were the same as the advisory values for slurry injected in spring to spring sown cereals, beet and maize. Advisory values for other application techniques, timings and crops range from 35-60% for cattle slurry and from 45-70% for pig slurry. For solid cattle manure, the advisory values range from 20-45%, considerably lower than the 65% value quoted in the AP. Similarly, the advisory values for poultry manure range from 20-65% compared with the AP value of 65%.

The Danish AP manure N efficiency coefficients are deliberately set at a high level (i.e. at levels that are achievable with best practice) to stimulate better timing and methods of manure application and to reduce the use of manufactured fertiliser N. The values also refer to a 10-year manure application history and assume that some longer-term mineralisation of organic N will occur.

**The Netherlands.** Relatively high manure N efficiency coefficients were specified in the Netherlands AP, because most manures are applied in spring (application of slurry and solid manure in autumn on arable clay and peat soils is banned) and the use of slurry shallow injection and band spreading techniques is widespread. Furthermore, the mineralisation of organic N from historic manure application is accounted for in the manure N efficiency coefficients.

The supporting information provided in the Dutch derogation request for the 3<sup>rd</sup> Nitrates Action Programme (MINLNV, 2005), indicated that a Working Group on application standards analysed manure N efficiency coefficients, using two different methods:

- empirical analysis of the results of fertilisation experiments in the field and;
- theoretical calculations of the N efficiency of different components in the manure.

In the latter method, manure N was divided into two parts:  $N_m$  and  $N_{org}$ .  $N_m$  is the mineral N present in the manure, which the British NVZ-AP and Defra “Fertiliser Manual (RB209)” (Defra, 2010) would describe as readily available N (mainly comprising ammonium-N, plus uric acid-N in poultry manures). The mineral N component is theoretically as efficient as manufactured fertiliser N, but some of the ammonium-N is likely to be lost in the form of ammonia after land spreading, so the efficiency of manure N will be lower than fertiliser N.  $N_{org}$  is the organic N in the manure; only a part of this becomes available in the first year after application, with the remainder becoming available during subsequent years following mineralisation. Combining the evidence and data available from these two methods, the Working Group agreed the first year N efficiencies (from both  $N_m$  and  $N_{org}$  sources) summarised in Table 3.

**Table 3: First-year N efficiencies reported by the Dutch Working Group (range due to different spreading methods).**

Manure type	Grassland	Arable land
Cattle slurry	51-58%	50-62%
Pig slurry	55-63%	60-75%
Slurry (autumn application)	-	19-23%

The Working Group considered that in a legal system these ranges and specific differences could not be used. Therefore, for pig slurry and brought in (i.e. imported onto a farm) cattle slurry a manure N efficiency coefficient of 60% was agreed. A value of 60% was also specified for cattle manure on farms with only cut grass (i.e. zero grazing), irrespective of whether this was slurry or solid manure. The autumn spreading of slurry on clay/peat arable soils was discouraged by progressively increasing the efficiency values from 30% in 2006 to 50% in 2008, with a total ban in 2009. The values in the AP reflect the mean results from theoretical and field data, and unlike Denmark, have not been set at the highest achievable (aspirational) levels.

A separate analysis was undertaken for N excretion during grazing. Conventional management systems are either day and night grazing (‘unlimited grazing’) or day-only grazing (‘limited grazing’), both over a grazing period of c.6 months. A lower N efficiency coefficient was assigned if cattle manure was excreted directly on to grassland. This lower value was not used directly, but was implied in the ‘mean’ N efficiency coefficient for cattle manure on farms with grazing, which represents the average of excretion during grazing and from handled (i.e. managed) slurry. For unlimited grazing, the mean N efficiency was c.30% and for limited grazing up to 45%. In the legal system, no differentiation was made between unlimited and limited grazing. Given the trend towards limited grazing, a figure of 35% was used in the AP for 2006-2007 and 45% thereafter.

A more recent report on measures to be implemented in the 4<sup>th</sup> Nitrates Action Programme (MINLNV, 2010) stated that the efficiency of livestock manure N was most importantly controlled by application timing and method, with the most effective policy to apply the manure at the start of the growing season. Also, efficiency was increased if manures were applied over a period of

several years. Notably, farmers on sandy soils were recognised as having the greatest flexibility in selecting favourable circumstances for applying livestock manure, as these soils can be travelled upon throughout much of the year, without creating compaction. Thus, the decision was made to increase the N efficiency coefficient for pig slurry from 60 to 70% on sandy soils (clay/peaty soils remain at 60%; Table 2). The aim of this change was that through the combination of a higher N efficiency coefficient for pig slurry, lower N application standards on some crops grown on sandy/loess soils and the adoption of innovative slurry application techniques, this would lead towards the achievement of desired groundwater quality in a large part of the sandy soil area of The Netherlands, within the course of the 4<sup>th</sup> Action Programme.

Schroder (2009) suggested that the legally imposed Dutch manure N coefficients should stimulate farmers to manage manure so that they fully exploit its ability to replace manufactured fertilisers (as far as is practically possible), and that additional legislation prescribing do's and don'ts should not be needed. Nevertheless, the Dutch legislation still contains rules on permitted spreading times (currently: 1 February – 1 September on sandy soils and 1 February – 15 September on clay soils; and from 2012: 15 February – 1 September on all soil types), minimum slurry storage capacities (from 2012: 6-7 months capacity) and prescribed application methods.

Whilst the manure N coefficients may seem ambitious, where manures are applied regularly, residual N effects from former applications can be added to the first year manure N coefficients (Schroder, 2009). These residual contributions are larger for farmyard manure-FYM (which contains a higher proportion of N in organic form which will mineralise into crop available N over time; typically 75-90% organic N) and somewhat smaller for slurry (which contains a smaller proportion of N in organic form; typically 30-55% organic N). The studies underpinning the standards (e.g. Schroder *et al.*, in press) have implicitly taken account of these longer-term effects. The manure N coefficients evolving from these studies have subsequently been translated into manure N standards, expressed as first year rather than longer term manure N efficiency coefficients (because farmers and extension services are most familiar with the concept of first year manure N coefficients).

**Northern Ireland.** In the Northern Ireland AP, manure N efficiency coefficients increased over the period 2007 to 2010 reflecting the improved efficiency of N use through the better timing of application relative to crop requirement (i.e. the movement of manure applications from late autumn/winter to spring/summer) and use of improved spreading methods (e.g. band spreading and shallow injection techniques) that reduce ammonia emissions to air.

**Eire.** The manure N efficiency coefficients initially implemented in the Southern Ireland AP were broadly in line with those recommended in Irish advice at that time. In the case of cattle slurry, advice was to use an N efficiency coefficient of 25% under best practice (spring application to grassland), reducing to 5% following summer application (Coulter, 2004). Notably, from 1<sup>st</sup> January 2010 cattle slurry N coefficients are 40% in the AP (Table 2). The efficiency improvements over time were mainly anticipated to be achieved through the introduction of improved slurry application techniques (Anon, 2006).

### **3.2 Help and support for farmers to achieve increased manure N efficiency coefficients.**

For some countries, information was available on the support made available to farmers to help them achieve the (sometimes challenging) manure N efficiency coefficients set in those Member States.

***The Netherlands.*** The Dutch Government recognised that increasing the manure N efficiency coefficient for pig slurry on sandy soils (along with other measures introduced in the 4<sup>th</sup> Action Programme) represented a considerable challenge for farmers, and therefore committed to provide support through the framework of an innovation programme (MINLNV, 2010). Two approaches are being adopted: developing innovation via R&D and the dissemination of innovative technologies.

*Developing innovation.* Research will be carried out to assess ways of taking better account in policy of differences between farms in their use of manures (for example yields, soil features and past use of manure). The feasibility of different policy options and their suitability for monitoring/compliance assessment will also be considered. Additionally, attention will be paid to different ways of processing manure (e.g. slurry/solids separation, anaerobic digestion), the nutrient supply characteristics of the products from the different processes and the effectiveness of different application methods. In the animal husbandry sector, research will look into ways to lower the nutrient content in manure via dietary manipulation.

*Knowledge dissemination.* This will involve demonstrating the positive aspects of innovative nutrient management methods in practical situations, leading to a change in overall management practices. Demonstrations at research institutions and on farms (within existing information-sharing networks) will contribute to this process, along with the testing of innovative measures on a larger scale. Where necessary and possible, the Dutch Government will provide targeted support for the implementation of innovative techniques and management measures, using money from European funds for agricultural and rural development policy. During the course of the programme, the extent to which innovative techniques are actually applied in practice will be assessed, to indicate at an early stage, whether this approach will produce environmental benefits and to also provide extra incentives for farmers.

The Dutch Government is also working on a number of fronts to improve the efficiency of livestock manure recycling, and in particular is encouraging initiatives to come from the marketplace. This is being facilitated by funding research, removing statutory restrictions and through communication and the transfer of knowledge to the agricultural industry. During the course of the 4th Action Programme, the focus will be on:

- reducing nutrient excretion from dairy cattle (primarily), by changing the composition of the diet. Research shows that changes to the composition of feed can help reduce urea-N excretion.
- research into the environmental effects and commercial feasibility of using specific manure processing methods and products to replace manufactured fertiliser use. The Government supports this research in the form of funding and knowledge transfer, and by granting exemptions for pilot projects;

- removing unnecessary legal obstacles to the export of livestock manure and manure processing products to arable and horticultural farming areas outside the Netherlands;
- instructing farmers on the efficient use of organic manures.

**Northern Ireland.** A Farm Nutrient Management Scheme (FNMS) was run in Northern Ireland to support farmers in complying with the Nitrates AP. Grant aid (at around 60%, up to a total grant of £51,000) was provided to assist farmers in upgrading their slurry (manure) storage facilities. Around 18% of farm businesses applied for a FNMS grant, covering c.40% of total cattle numbers in Northern Ireland. In the region of £120 million was provided in grant aid under FNMS; with the majority of spend (>90%) on the upgrading of slurry storage facilities. Implementation of the AP was backed up by an advisory campaign and investment in R&D to develop practices to increase manure N use efficiency.

**Eire.** The Republic of Ireland (Ministry of Agriculture, Fisheries and Food) provided grant aid (in the range 60-75%) for upgrading slurry (manure) storage facilities and for the purchase of low (ammonia) emission application equipment (i.e. band spreaders and shallow injectors). At an advisory level, Teagasc (the Irish Advisory Service) promoted the importance of spring slurry application timings to minimise ammonia and nitrate losses, and to maximise manure N use efficiency (S. Lalor, pers. comm).

A number of research projects were funded to enhance the knowledge base to improve manure N use efficiency (focussed on cattle and pig slurry) and to reduce the variability of manure nutrient utilisation by grassland and tillage crops (e.g. Dowling *et al.*, 2009; Lalor *et al.*, 2009; Hackett and Young, 2009; Hoekstra *et al.*, 2009).

## 4. METHODOLOGY FOR DERIVING MANURE NITROGEN EFFICIENCY COEFFICIENTS FOR ENGLAND (AND BRITAIN)

In this study, we explored three methodologies to provide a robust evidence base to underpin revised manure N efficiency coefficients for the next NVZ-AP in England (Britain) from 2013-16, viz:

1. Using manure N efficiency values (mean and ranges) from a database of *field experimental studies* in England and Wales.
2. Setting values based on *recommended* (i.e. Defra “Fertiliser Manual (RB209)”) manure N efficiencies and information on typical manure *application timings* and techniques.
3. Setting *maximum practically achievable* values based on Defra “Fertiliser Manual (RB209)” manure N efficiencies.

### 4.1 Manure N efficiency database

A database of manure N efficiency coefficients was collated to validate predictions of manure fertiliser N replacement values made by the MANNER-NPK decision support system (Nicholson *et al.*, 2008; Nicholson *et al.*, 2009; Nicholson *et al.*, 2010). The database consisted of manure N efficiency measurements from field experiments where manures (cattle slurry and FYM, pig slurry and FYM, and poultry manure) were applied in different geographical locations throughout England and Wales, during the period 1980 to 2001 (see Appendix I for paper references that have contributed to the database). A range of manure application timings, techniques and soil incorporation methods, across a range of soil types and environmental conditions were included. Also, we added more recent data from cattle/pig FYM N efficiency measurements in Defra project NT2008 (Williams *et al.*, 2008) to the original database used to validate MANNER-NPK. Additionally, the database was rationalised to ensure that experimental data were only included where:

- slurry was broadcast applied, as this is still the most commonly used slurry application method in England.
- $\leq 250$  kg total N/ha were applied (i.e. that the application rate did not exceed the NVZ field N limit of 250 kg/ha total N per year);
- if manure was applied at a range of application rates to a site at the same time, the mean manure N efficiency overall application rates was used (otherwise these sites would have been over-represented in the database).

Following the additions and rationalisations, the database consisted of 127 measurements of manure N efficiency, across a range of sites with different land uses (i.e. cereals, potatoes, sugar beet and grassland), application timings, soil incorporation strategies and soil types (Table 4). The mean and range of manure N efficiencies for spring/summer and autumn/winter timings of each manure type group are summarised in Table 4.

**Table 4: Summary of ADAS database of manure N efficiency measurements.**

Manure type	Total	Experiment date			Land use		Soil incorporation strategy		Application timing			
		Pre-1990	1990-1999	Post-2000	Grass-land	Arable	Incorporated	Unincorporated	Spring (Feb-Apr)	Summer (May-Jul) <sup>1</sup>	Autumn (Aug-Oct)	Winter (Nov-Jan)
Cattle slurry	52	46	6	0	47	5	1	51	28	21	2	1
Pig slurry	6	0	6	0	0	6	2	4	3	0	3	0
Layer manure	11	1	10	0	4	7	2	9	5	3	1	2
Broiler litter	33	2	29	2	2	31	17	16	14	0	13	6
Cattle FYM	9	1	1	7	7	2	4	5	4	0	5	0
Pig FYM	16	0	2	14	14	2	11	5	1	0	5	10
<b>Total</b>	<b>127</b>	<b>50</b>	<b>54</b>	<b>23</b>	<b>74</b>	<b>53</b>	<b>37</b>	<b>90</b>	<b>55</b>	<b>24</b>	<b>29</b>	<b>19</b>

<sup>1</sup>Surface applied to grassland

For cattle and pig slurry, the mean N efficiency of the autumn/winter application timings at 14 and 12%, respectively, was lower than the minimum manure N efficiency specified in the NVZ-AP in Britain from both 2009 and 2012 (Table 5). For cattle slurry, the mean N efficiency of the spring/summer application timings (25%) was greater than the value specified in the NVZ-AP from 1<sup>st</sup> January 2009 (20%), but lower than the value from 1<sup>st</sup> January 2012 (35%). For pig slurry, the mean N efficiency of the spring/summer application timings (47%) was similar to the value specified in the NVZ-AP from 1<sup>st</sup> January 2012 (45%). For poultry manure, there was little difference in N efficiency between the autumn/winter (mean=27%) and spring/summer timings (mean=30%), and both were similar to the value in the NVZ-AP from 1<sup>st</sup> January 2012 (30%). For FYM, the mean N efficiency of the autumn/winter application timings (10%) was the same as the value specified in the NVZ-AP (10%), with a greater efficiency from spring/summer timings at 20% (although the latter was based on only 5 experimental measurements).

**Table 5: Summary of measured manure N efficiencies and values specified in the NVZ-AP (% of total N applied available to next crop)**

Manure type	Autumn/winter timings			Spring/summer timings			NVZ-AP	
	Mean	Range	n*	Mean	Range	n*	From 1 <sup>st</sup> January 2009	From 1 <sup>st</sup> January 2012
Cattle slurry	<b>14</b>	6-20	3	<b>25</b>	7-59	49	20	<b>35</b>
Pig slurry	<b>12</b>	12-13	3	<b>47</b>	45-49	3	25	<b>45</b>
Poultry manures	<b>27</b>	8-57	22	<b>30</b>	8-45	22	20	<b>30</b>
Cattle and pig FYM	<b>10</b>	1-25	20	<b>20</b>	4-37	5	10	<b>10</b>

\*number of experimental measurements



## 4.2 Manure N efficiency recommendations in the “Fertiliser Manual (RB209)”

### 4.2.1 Derivation of manure N efficiencies

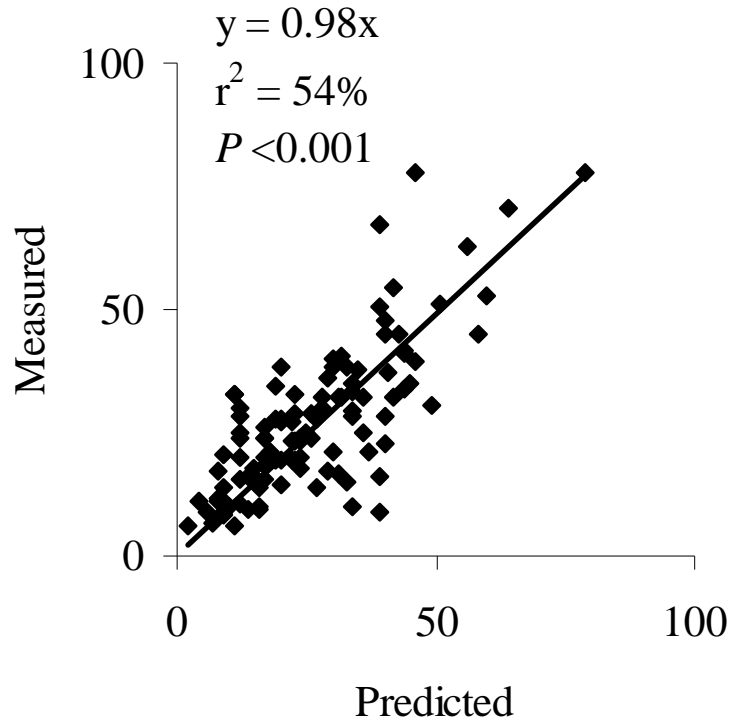
The manure N efficiencies published in the “Fertiliser Manual (RB209)” (Defra, 2010) were generated using the MANNER-*NPK* software (Nicholson *et al.*, 2009; Nicholson *et al.*, 2010). The original version of MANNER (Chambers *et al.*, 1999) and the enhanced MANNER-*NPK* software were developed to synthesise knowledge on N transformations and losses following the land spreading of organic manures (e.g. on ammonia emissions and denitrification losses as di-nitrogen and nitrous oxide to air, nitrate leaching losses to water and the mineralisation of manure organic N). And, to quantify crop available N (P, K, Mg and S) supply, taking into account manure type, manure total and readily available N contents, dry matter, speed and method of soil incorporation, application technique (for slurry), timing of application, soil type and moisture content, windspeed and overwinter rainfall.

To ensure that MANNER-*NPK* provided reliable quantitative assessments of manure crop available N supply across a range of soil types and climatic conditions, MANNER-*NPK* predictions were validated against actual fertiliser N replacement values measured in field experiments (see Appendix I for paper references that have provided validation data). The validations showed that there was good agreement ( $P < 0.001$ ) between measured cattle and pig manure fertiliser N replacement values from a range of cereal and grassland field experiments and MANNER-*NPK* predicted values, Figure 1 i/ii (Nicholson *et al.*, 2010). Similarly, there was good agreement ( $P < 0.01$ ) between measured poultry manure fertiliser N replacement values and MANNER-*NPK* predicted values, Figure 2 (Nicholson *et al.*, 2010).

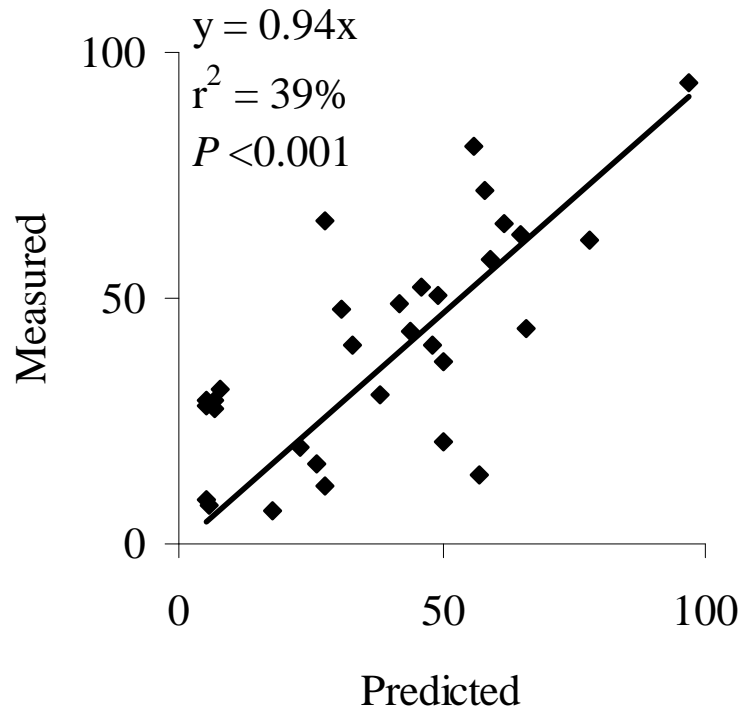
These results confirm that MANNER-*NPK* can provide robust and quantitative estimates of manure fertiliser N replacement values (i.e. manure N efficiency) across a range of manure types, application timings and methods, soil types and environmental conditions. Hence, MANNER-*NPK* was used to produce the manure N efficiency ‘look-up’ tables in the “Fertiliser Manual (RB209)” (Defra, 2010).

Figure 1. Measured vs. MANNER-NPK predicted fertiliser N replacement values (kg/ha) for i) cattle manures (slurry and FYM) and ii) pig manures (slurry and FYM)

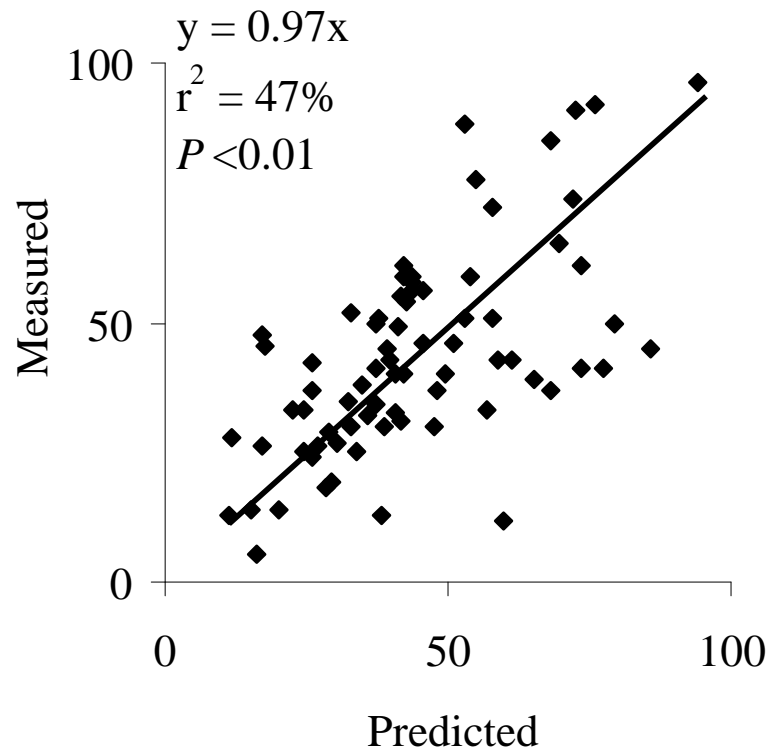
i



ii



**Figure 2. Measured vs. MANNER-NPK predicted fertiliser N replacement values (kg/ha) for poultry manures**



#### **4.2.2 Recommended manure N efficiencies**

Recommended manure N efficiencies from the “Fertiliser Manual (RB209)” (Defra, 2010) are summarised in Table 6, assuming that all the manures were surface applied (i.e. they were not soil incorporated following spreading).

Manure N efficiencies were greatest following spring (February–April) and summer (May–July) application timings, with lower efficiencies following autumn and winter timings, principally as a result of over-winter nitrate leaching losses. Soil type was also an important factor, with manure N efficiencies following autumn (and to a lesser extent winter) timings much lower on sandy/shallow soils than medium/heavy soils, due to greater over-winter nitrate leaching losses.

**Table 6: Recommended manure N efficiencies for different surface spread<sup>1</sup> application timings.**

Manure type	Autumn (Aug-Oct) <sup>2</sup>		Winter (Nov-Jan) <sup>3</sup>		Spring (Feb-Apr)	Summer use on grassland
	Sandy/shallow	Medium/heavy	Sandy/shallow	Medium/heavy	All soils	All soils
Cattle slurry (6% dry matter) <sup>4</sup>	5 (10)	25 (30)	25	25	35	25
Pig slurry (4% dry matter) <sup>5</sup>	10 (15)	30 (35)	35	35	50	50
Layer manure <sup>6</sup>	10 (15)	25 (30)	25	25	35	35
Broiler litter <sup>6</sup>	10 (15)	25 (30)	20	25	30	30

(use for grassland and under oilseed rape cropping)

<sup>1</sup>Under the current NVZ-AP, incorporation of slurry and poultry manure as soon as practicable (and within 24 hours) is a requirement for spreading onto bare soil and stubble, unless slurry is applied with a band spreader or injected into the soil.

<sup>2</sup>In NVZs on sandy/shallow soils, applications in the 'autumn period' cannot be made on tillage land after 1<sup>st</sup> August (or after 15<sup>th</sup> September where a crop is sown) or on grassland after 1<sup>st</sup> September.

<sup>3</sup>In NVZs, applications in the 'winter period' can only be made to sandy/shallow soils from 1<sup>st</sup> January and on other soils from 16<sup>th</sup> January.

<sup>4</sup>Soil incorporation within 6 hours of spreading can further increase N efficiency by up to 10%

<sup>5</sup>Soil incorporation within 6 hours of spreading or the use of band spreading/shallow injection techniques can further increase N efficiency by up to 10%

<sup>6</sup>Soil incorporation within 24 hours of spreading can further increase N efficiency by up to 15%

To provide an estimated of manure N efficiencies presently being achieved 'on-farm' we used manure timing data from detailed manure management practice surveys reported by Smith *et al.* (2000; 2001a; 2001b), Table 7. Although these data are from the late 1990s, it is unlikely that there have been significant changes in manure application timings, as there has been little recent investment in manure (slurry) storage facilities and previous NVZ rules (Defra, 2002) only had closed periods for the spreading of high readily available N manures (i.e. slurries and poultry manures) on sandy/shallow soils. As a result of the closed period for spreading high readily available N manures being extended to all soil types (Sl, 2008), predictions were made of likely changes in manure application timings (Anon, 2007), Table 8. The predictions reflected reductions in autumn/winter applications to sandy/shallow soils (closed period 1 September–31 December on grassland; 1 August–31 December on tillage land) and to other soils (closed period 15 October–15 January on grassland; 1 October–15 January

on tillage land). Also, there was a predicted increase in applications during the spring and summer periods to accommodate the ‘displaced’ autumn/winter applications (Table 8).

**Table 7: Estimated present day (Smith *et al.*, 2000; 2001a; 2001b) manure application timings (% of manure applied)**

Manure type	All soils			
	Spring (Feb-Apr)	Summer (May-July)	Autumn (Aug-Oct)	Winter (Nov-Jan)
Cattle slurry*	38	12	21	30
Pig slurry	28	18	29	25
Layer manure	33	9	43	15
Broiler litter	22	12	58	8

\*Mean of dairy and beef slurry

**Table 8: Predicted manure application timings reflecting NVZ-AP closed period rules for spreading high readily available N manures (% of manure applied)**

Manure type	Sandy/shallow soils				Other soils			
	Spring (Feb-Apr)	Summer (May-July)	Autumn (Aug-Oct)	Winter (Nov-Jan)	Spring (Feb-Apr)	Summer (May-July)	Autumn (Aug-Oct)	Winter (Nov-Jan)
Cattle slurry*	62	19	12	7	61	20	19	0
Pig slurry	54	30	8	8	48	27	25	0
Layer manure	75	14	6	5	52	12	36	0
Broiler litter	55	41	2	2	33	21	46	0

\*Mean of dairy and beef slurry

The data in Tables 6 and 8 were then combined to estimate the manure N efficiencies likely to be achieved on farms at the end of the NVZ-AP in 2012, assuming that c.10% of soils in England and Wales were sandy/shallow and c.90% were medium/heavy (Table 9).

The estimated manure N efficiency values at the end of the NVZ-AP in 2012 are close to the minimum manure N efficiency coefficients stipulated in the NVZ-AP rules (SI, 2008), Table 9.

**Table 9: Estimated manure N efficiencies (%) at the end of the NVZ-AP in 2012 in comparison with current NVZ-AP values.**

Manure type	Estimated N efficiency*	NVZ-AP	
		From 1 <sup>st</sup> January 2009	From 1 <sup>st</sup> January 2012
Cattle slurry	32	20	35
Pig slurry	46	25	45
Layer manure	32	20	30
Broiler litter	28	20	30

\*Assumes manures are surface applied and not soil incorporated

#### 4.2.3 Maximum achievable manure N efficiencies

In Denmark, minimum manure N coefficients in the AP are set at a high level to stimulate better timing and methods of manure application (see Section 3). In order to explore the maximum manure N efficiencies that could be achieved in England by encouraging farmers to adopt ‘best practice’ manure application strategies, we assumed that all manures would be applied in spring/summer (rather than in autumn/winter where higher over-winter nitrate leaching losses are likely to occur). Also, we assessed the likely effects of using improved slurry application techniques (i.e. band spreading and shallow injection equipment, see Plates 1-3) to increase manure N efficiency through reducing ammonia volatilisation losses. *Note:* Improved slurry spreading equipment is not commonly used in England and Wales at the present time; the “Inventory of Ammonia Emissions from UK Agriculture–2008” (Misselbrook *et al.*, 2009) estimates that c.4% of cattle slurry and c.30% of pig slurry is spread using low (ammonia) emission techniques. Additionally, soil incorporation (e.g. by plough or disc) within a few hours of manure application can increase manure N efficiency, again through reducing ammonia losses; although this technique can only be used on tillage land.

**Plate 1: Trailing hose slurry band spreader**



**Plate 2: Trailing shoe slurry band spreader**



**Plate 3: Shallow injection slurry applicator**



Recommended manure N efficiencies published in the “Fertiliser Manual (RB209)” for spring and summer application timings, using a range of application strategies, are summarised in Table 10. For cattle and pig slurry, the highest N efficiencies were from spring application using shallow injection techniques (45 and 60%, respectively). Improvements in N efficiency were also achieved through using band spreading techniques and through the rapid soil incorporation of slurry within 6 hours of spreading. For poultry manures, soil incorporation within 24 hours increased efficiency N by 10-15% (compared with no soil incorporation). In the case of FYM, soil incorporation within 24 hours of land spreading (although of benefit in reducing odour nuisance and surface run off risks) was of little benefit (<5%) in improving manure N efficiency, as the ammonium-N content of FYM is relatively low.

**Table 10: Recommended manure N efficiencies (%) from spring and summer timings using different management strategies (Defra, 2010).**

Manure type	Spring applied (Feb–Apr)				Summer use on grassland (May–July)			
	Surface applied	Soil incorporated <sup>3</sup>	Band spread	Shallow injected	Surface applied	Soil incorporated <sup>3</sup>	Band spread	Shallow injected
Cattle slurry <sup>1</sup>	35	40	40	45	25	n/a	30	35
Pig slurry <sup>2</sup>	50	60	55	60	50	n/a	55	60
Layer manure	35	50	n/a	n/a	35	n/a	n/a	n/a
Broiler litter	30	40	n/a	n/a	30	n/a	n/a	n/a
FYM <sup>4</sup>	10	10	n/a	n/a	10	n/a	n/a	n/a

<sup>1</sup>6% dry matter

<sup>2</sup>4% dry matter

<sup>3</sup>Incorporated within 6 hours for slurries and 24 hours for solid manures

<sup>4</sup>Old FYM – stored for more than 3 months (Defra, 2010)

n/a: not applicable



### 4.3 Recommended manure N efficiencies for next NVZ-AP

To drive up on-farm manure N use efficiency it will be necessary to encourage farmers to continue to change manure application timings and to improve slurry management and spreading practices, viz:

- Apply greater amounts of slurry (manure) in spring/summer rather than in autumn, although this will require increased investment in slurry storage facilities (typical costs are £30-£40/m<sup>3</sup> for an above-ground steel or concrete store and £15-£25/m<sup>3</sup> for a lagoon). *Note:* on medium/heavy soils this is likely to increase surface water pollution risks, as a result of increased drainflow/surface runoff losses of phosphorus, ammonium-N and microbial pathogens – these ‘pollution swapping’ issues are being evaluated in the Defra “Cracking Clays” studies (projects WQ0118 and AQ0111).
- Increase the use of slurry band spreading and shallow injection techniques
- Increase the rapid soil incorporation of manures.
- Increase the use of low dry matter slurries which have a higher N use efficiency than higher dry matter slurries.

Based on manure N efficiencies in the “Fertiliser Manual (RB209)”, which were produced using the MANNER-*NPK* software and validated against measured field experimental data, we recommend adopting the minimum manure N efficiency coefficients summarised in Table 11.

**Table 11. Recommended manure N efficiency coefficients for adoption in the next NVZ-AP in England**

Manure type	NVZ-AP	Recommended values in next NVZ-AP
	From 1 <sup>st</sup> January 2012	From 1 <sup>st</sup> January 2016
Cattle slurry	35	<b>40</b>
Pig slurry	45	<b>50/55</b>
Poultry manures	30	<b>35</b>
FYM	10	<b>10/15</b>

These values may seem ambitious (to some), however, where manures are applied regularly there is good evidence from the UK (e.g. Chadwick *et al.*, 2000; Williams *et al.*, 1999; 2001) and other European countries (e.g. Schroder *et al.*, 2007) to show that previous manure applications will supply N to following crops through the mineralisation of organic N. Moreover, recent enhancements to the MANNER software (i.e. MANNER-*NPK*) provide guidance on manure crop

available N supply to following crops i.e. in the second year following a previous manure application (Table 12).

**Table 12. MANNER-NPK estimates of N available in crop year 2**

Manure type	Crop N available in year 2 (% total N applied)
Dairy slurry	2
Pig slurry	3
Fresh cattle/pig FYM	3
Layer manure	3
Broiler litter	4

## 5. POTENTIAL ENVIRONMENTAL IMPACTS AND OTHER ISSUES ASSOCIATED WITH CHANGING MANURE MANAGEMENT PRACTICES TO INCREASE NITROGEN EFFICIENCY

The potential environmental impacts and other issues associated with the following changes in manure management practices were assessed:

- Increased spring/summer manure applications;
- increased adoption of slurry/band spreading or shallow injection techniques;
- increased rapid soil incorporation of manures.

### 5.1 Increased spring/summer manure applications

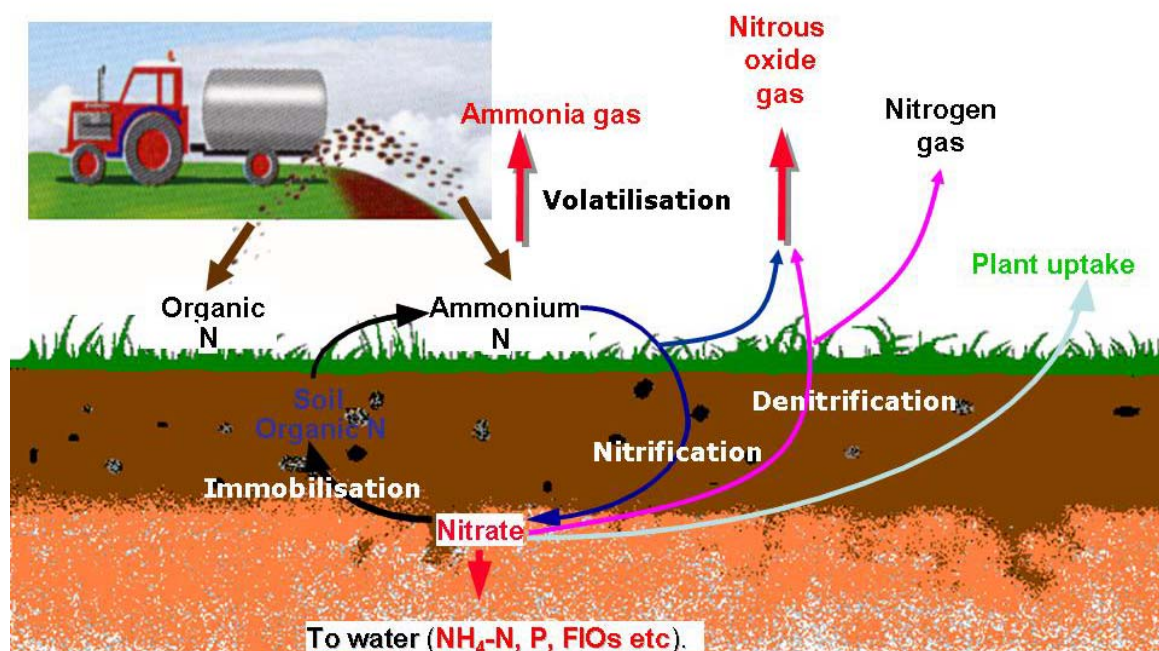
**Environmental impacts.** A move towards the increased application of manures in spring (and summer on grassland) will decrease the risk of nitrate leaching losses.

The additional spring/summer applications would mainly involve top-dressing onto growing grassland and combinable (e.g. winter cereals and oilseed rape) crops. This increase in spring top-dressing to combinable crops would be likely to increase ammonia (NH<sub>3</sub>) volatilisation losses (Misselbrook *et al.*, 2004), as would the increased amounts of cattle slurry applied to grassland in summer (MANNER-NPK; Defra 2010). Also, as a result of these enhanced ammonia losses indirect nitrous oxide (N<sub>2</sub>O) emissions would increase. However, moving cattle slurry applications from late autumn/winter to spring on free draining grassland soils has been shown to reduce direct N<sub>2</sub>O emissions by c.50% (Thorman *et al.*, 2007). *Note:* Defra project AQ0111 is presently evaluating the effect of contrasting slurry application timings on direct and indirect N<sub>2</sub>O, and NH<sub>3</sub> emissions from medium/heavy soil types.

The risk of transfer of manure-derived pollutants (phosphorus-P, ammonium-N, microbial pathogens and oxygen depleting matter) to watercourses would increase because of the greater risk of drainflow/surface runoff losses from spring compared with autumn applied manures (and in particular slurries). Results from Defra Project ES0106 (Developing Integrated Land Use and Manure Management Strategies to Control Diffuse Nutrient Losses from Drained Clay Soils: BRIMSTONE-NPS) showed that on drained clay soils, slurry applications to 'wet' soils in spring can result in elevated ammonium-N and P concentrations in drainage waters (an example of 'pollution swapping'), see Figure 4. *Note:* an assessment of water pollution risks from a range of diffuse pollutants from contrasting slurry applications timings is being undertaken in Defra Project WQ0118 (Understanding the Behaviour of Livestock Manure Multiple Pollutants through Contrasting Cracking Clay Soils).

There is also an increased risk of soil compaction from spring compared with autumn manure application timings.

Figure 4: N transformations and losses following manure application to soil



**Other issues.** Increasing the proportion of slurry applied in spring will only be possible on farms that have sufficient storage capacity to permit an application choice. Also, even where storage is adequate for normal conditions, exceptional weather or poor planning can create a situation where stores are full and land spreading is the only option. Notably, there is a much wider window of spreading opportunities on grassland, because of the longer growing season than for arable crops.

## 5.2 Slurry band spreading and/or shallow injection

**Environmental impacts.** The increased use of slurry band spreading and/or shallow injection techniques will increase (to a small extent) the potential for nitrate leaching following autumn application timings and also direct/indirect N<sub>2</sub>O emissions, as more mineral N is retained in the soil. However, as a result of more manure N being retained in the soil, less manufactured fertiliser N will be needed to meet crop needs, hence, there will be a net benefit in terms of N use efficiency at the farm level.

The use of slurry band spreading or shallow injection techniques will decrease ammonia volatilisation losses compared with surface broadcasting; typically by 30% for trailing hose and trailing shoe applications to short grass, 60% for trailing shoe applications to long grass and 70% for shallow injection. Odour nuisance will also be reduced compared with broadcasting. Shallow injection (particularly of dilute slurries) on sloping land can result in run-off along the injection slots, particularly where there is smearing of the injection slot.

Band spreading and shallow injection equipment is generally heavier and requires more horse power to operate than broadcast spreading equipment, and can result in greater risks of soil compaction.

**Other issues.** Applying slurry beneath the crop canopy (grassland or arable) avoids direct crop contamination. For grassland, this reduces the required period between slurry application and silage harvest/grazing, and importantly extends the window of opportunity for slurry application (Defra, 2010; Chambers *et al.*, 2001a;b). Similarly for arable crops, the use of band spreading equipment extends the application window later into the spring when crop height and the risks of leaf scorch normally exclude conventional broadcast slurry application. Band spreading and shallow injection equipment also delivers slurry more uniformly across the entire application width in comparison with conventional broadcast application.

Band spreading and shallow injection equipment is relatively expensive (£15-30k). Also, band spreading and shallow injection operations are generally slower than conventional surface broadcast application, so there may be some small added operational costs. Many trailing hose machines have a boom width of 12-18m (although 24m booms are now available), so for combinable crops with greater tramline spacings than the boom width, slurry application will require travelling on the crop between tramlines, which may result in some crop damage (depending on growth stage at the time of application). Additionally, shallow injection equipment operates less effectively on stony and heavy soils (because of the inability of the injector to cut a slot in the soils), and can cause grassland sward damage under dry soil conditions (Laws *et al.*, 2007).

The widespread uptake of such improved slurry/spreading equipment is likely to be limited, unless there are financial incentives to invest in new machinery (e.g. low or free interest loans, grants or tax breaks).

### 5.3 Rapid soil incorporation of manures

**Environmental impacts.** Rapidly incorporating manures into the soil in autumn will retain mineral N in the soil which would otherwise be lost as ammonia, but will increase (to a small extent) the potential for nitrate leaching losses to water and direct/indirect N<sub>2</sub>O emissions to air. If the rapid cultivation policy damages soil structure (which is more likely for spring than autumn applications), this may compromise crop yields and result in applied N (from both organic manure and manufactured fertiliser N sources) being poorly utilised by crops and at risk of leaching over the following winter drainage period. In addition, if a plough (rather than tines or discs) was used for soil incorporation, the manure would be buried at a greater depth in the soil (20-30 cm) and there would be a greater potential for nitrate leaching losses (Chambers *et al.*, 1999), particularly on sandy/shallow soils.

The effect on NH<sub>3</sub> emissions will depend on the time period between manure application and soil incorporation, and also on the cultivation technique employed. There is a considerable decrease in the ammonia abatement achieved if soil incorporation is delayed; incorporation as soon as practically possible after application should be the aim. Also, the rapid soil incorporation of manures will reduce the risk of pollutant losses (e.g. P, ammonium-N, microbial pathogens etc.) in surface runoff and will reduce soil surface hydrological connectivity with field drains.

**Other issues.** The soil incorporation of manures is a part of normal tillage land field operations. However, the rapid soil incorporation of manures (within hours) does require increased management planning and can result in increased staff resources to co-ordinate activities.

## 6. RECOMMENDATIONS FOR FUTURE RESEARCH TO IMPROVE N EFFICIENCY

- There have been *few studies* in recent years (post 2000) that have *quantified the fertiliser N replacement* value of cattle and pig slurry applications to grassland and combinable crops (i.e. winter and spring cereals and oilseed rape). The focus in the last decade has mainly been on quantifying nitrate leaching losses and ammonia and nitrous oxide emissions following manure spreading (i.e. on environmental impacts).
- The potential benefits of *slurry separation* and *anaerobic digestion* on N use efficiency requires further research – at present the Defra “Fertiliser Manual (RB209)” does not provide any recommendations on the N use efficiency of separated or digested slurry.
- To quantify the effects of ‘new’ low ammonia emission poultry housing systems (e.g. on-belt drying of layer manures) and management practices (e.g. broiler litter additives) on poultry manure N use efficiency.
- To quantify the effects of pig slurry acidification, which is being adopted in some Member States (e.g. Denmark) to increase pig slurry N use efficiency also merits investigation.

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