What impact does the alteration of timing to slurry applications have on leaching of nitrate, phosphate and bacterial pathogens? A Rapid Evidence Assessment.

Authors: Alice Waterson and Nicola P Randall
Centre for Evidence Based Agriculture, Harper Adams University, Newport Shropshire TF10 8NB
Correspondence: nrandall@harper-adams.ac.uk 44(0)1952 815347

This work was commissioned by the Department of Food and Rural Affairs (Defra) and was funded by the Natural Environment Research Council (NERC).

Executive summary

Background

Approximately 90 million tonnes of farm manures are applied to agricultural land in the UK each year. This application of manures and slurries provides a highly valuable source of plant available nutrients to agricultural soils with an estimated fertilizer value of £150 million per year, but there is increasing concern about potential detrimental effects on the natural environment and water quality. Slurry application poses significant risk of diffuse pollution to water courses, through nitrate, ammonium, phosphate and microbial pathogen losses.

Regulations restrict the application of manures on all soil types in the late autumn-winter period in order to minimise nitrate leaching (and other nutrient losses) following manure applications, with the length of the 'closed period' varying according to soil type and land use.

REA Process

This Rapid Evidence Assessment (REA) aimed to compile and describe available evidence on the effect of the alteration of slurry application timing for delivering an improved water environment (focussing on nitrate, phosphate and bacterial pathogens as components of water pollution), to establish a general consensus on the effectiveness of this intervention, to assess the quality of available evidence and to identify potential gaps in current knowledge.

From an initial 7903 potentially relevant articles initially found, 34 relevant studies were collated into a searchable database of research and the findings summarised. Eight studies were evaluated for the robustness of research and effectiveness of interventions.

Key findings

Individual studies compared a wide variety of different timings, and often recorded variable or unclear results for best application timing to reduce leaching. Many of the studies were only read to abstract, or had confounding factors, but in very general terms autumn was most commonly identified as the worst timing for leaching (particularly of Nitrates), and this confirmed in 7 of 8 studies that were available at full text and did not have confounding factors. Again in very general terms, spring was most often identified as the best application time for reduced leaching. Winter applications also reduced leaching when compared with autumn, although this was less frequently studied than autumn versus spring timings.

Implications for policy and further research

The findings broadly support current policy that restricts slurry application during the autumn. The research most frequently demonstrated that autumn application poses the most significant risks in terms of nutrient and pollutant regulations. Winter applications were sometimes found to lead to less leaching than autumn applications, but this REA did not consider other potential impacts of winter applications (such as negative impacts of machinery on waterlogged soils etc.). Spring applications were most frequently found to reduce the impacts of leaching when compared to autumn applications.

The research found was dominated by studies into leaching of Nitrates following slurry applications. This highlights a potential research gap, as Phosphates and Faecal Indicator Organisms also have the potential to cause significant environmental and health impacts.

It would be useful for future studies to report changes to pollutants quantitatively (e.g. percentage reduction).

The reporting and/or design of studies was such that it was often not possible to ascertain the study whether or not impacts were due to the variations in slurry timings or to other factors investigated in the same study. Clear reporting of study design and of individual interventions would increase the value of future research.

Background

Application of fertilizers, both organic and inorganic, is commonplace in agricultural systems worldwide. In England and Wales, approximately 16% of tilled land and approximately 48% of grasslands receive annual applications of manures (Chambers *et al.* 2000). This process is highly valuable in terms of soil quality, crop production and also as an effective means of waste management.

Approximately 90 million tonnes of farm manures, supplying 450,000 tonnes of nitrogen are applied to agricultural land in the UK each year (Williams *et al.* 2006). In addition to these quantities, it is estimated that an additional 45 million tonnes of excreta are deposited directly onto land through grazing livestock. This application of manures and slurries provides a highly valuable source of plant available nutrients to agricultural soils. For example, in Spring 2014 an application of 30m^3/ha pig slurry equates to £130 fertiliser value/ha, and cattle farmyard manure applied at 40 tonnes/ha equates to £259/ha (based on inorganic fertilizer trade costs).

Despite the benefits of these manures to the agricultural sector, there is increasing concern about potential detrimental effects on the natural environment and water quality. Slurry application poses significant risk of diffuse pollution to water courses, through nitrate, ammonium, phosphate and microbial pathogen losses, and of air pollution through losses of ammonia and nitrous oxide (Nicholson *et al* 2011). Water pollution from agricultural sources can have significant and detrimental impacts on human health, water quality and the natural environment. High nitrate and phosphate levels in drinking water are considered unsafe for human consumption. The presence of microbial pathogens, known as faecal indicator organisms (FIOs), can also contaminate drinking waters, along with bathing waters and shellfish production. High phosphorus and nitrate levels in the environment can also lead to eutrophication, disturbing the balance of organisms present in an ecosystem and ultimately can cause sections of water body being killed off as a result of oxygen removal (Defra 2012*a*).

In recent decades, concerns regarding the extent of diffuse pollution as a result of agricultural pollution have grown, with agricultural activities believed to contribute very significantly to levels of aquatic pollution and estimated to be the source of 28% of phosphates, 70% of nitrates and 76% of sediments in UK rivers (Collins *et al. 2009*, Edwards *et al.* 2008). UK catchments dominated by agricultural land use also have elevated levels of bacterial pathogen counts (Kay *et al.* 2008).

Such concerns have contributed to the development and implementation of the European Water Framework Directive (WFD), whereby European member states are legally committed to tackling water pollution through this legislation and additional directives including the Nitrates Directives, the Ground Water Directive and the Bathing Water Directive. Adopted in 2000, the overall aim of the WFD is for the ‘water bodies’ and ‘protected areas’ within each River Basin District to achieve 'good status' by 2015 (Natural England 2013).

The Nitrates Directive specifically targets agricultural pollution and aims to protect water quality across Europe by preventing nitrates from agricultural sources polluting ground and surface waters and by promoting the use of good farming practices (European Commission 2010). In the UK, Nitrate Vulnerable Zones (NVZs) are used to implement some of this policy on a national scale (Defra 2011). Substantially revised in 2008, the Nitrate Vulnerable Zone Action Programme covers approximately 58% of agricultural land in England(Defra 2013). This regulation requires the effective planning, calculation, application and recording of mineral fertilizers and livestock manure in accordance with the field limit, farm limit and crop nitrogen requirement, the effective and appropriate storage of slurry and the restriction of slurry application during ‘closed periods’ (Defra, 2012*b*).

With particular focus on the timing of slurry application, NVZ regulations restrict the application of manures with readily available nitrogen contents greater than 30% of total nitrogen (i.e. pig/cattle slurries and poultry manures) on all soil types in the late autumn-winter period. The ‘closed spreading periods’ are designed to minimise nitrate leaching (and other nutrient losses) following manure applications, with the length of the ‘closed period’ varying according to soil type and land use (Nicholson *et al* 2011). From a farm management perspective however, the timing of slurry application is a difficult issue, with slurry storage capacity and the ability for heavy application machinery to operate on potentially water-logged soils both needing consideration.

The timing of slurry application is thought to have an impact on the scale of subsequent nutrient and microbial losses, and consequently the potential magnitude of pollution impact. Autumn applications are widely considered to increase the risk of nitrate leaching losses, regardless of soil type. Nitrogen uptake during the autumn and winter period is generally low, and typical seasonal rainfall patterns can wash manure-derived nutrients and pathogens beyond crop rooting depth and consequently lead to leaching (Nicholson *et al* 2011).

Objective of the review

This Rapid Evidence Assessment (REA) aimed to compile and describe available evidence on the effect of the alteration of slurry application timing for delivering an improved water environment (focussing on nitrate, phosphate and bacterial pathogens as components of water pollution), to establish a general consensus on the effectiveness of this intervention, to assess the quality of available evidence and to identify potential gaps in current knowledge.

Primary question

This study aimed to address the following question:

What impact does the alteration of timing to slurry applications have on leaching of nitrate, phosphate and bacterial pathogens?

This is an impact question designed specifically to assess the effectiveness of alternating the timing of slurry application as a policy driven intervention method, on the selected components of water pollution.

This question can be broken down into its PICO components:

PICO element and definition	**PICO element within this REA**
Population – the subject to which the intervention is applied	Water pollutants (nitrate, ammonia, phosphates and bacterial pathogens)
Intervention – the policy or related intervention/exposure such as management regime	Alteration of timing of slurry application
Comparator – control example of no intervention or alternative	Absence of slurry application or application during a different period
Outcome	Impact on water quality

Primary outcomes measured were:
Nitrate, phosphate and bacterial pathogens as components of water pollution.

Methods

The method used in the development of the Rapid Evidence Assessment was based on draft guidance for the production of Quick Scoping Reviews and Rapid Evidence Assessments produced by the Department of Environment, Food and Rural Affairs (Defra) (Miller *et al*, 2013)

Searches

A comprehensive search was undertaken using multiple information sources in order to capture an unbiased sample of literature. The search strategy was designed to identify both published unpublished (grey) literature.

An initial scoping search was performed to test for specificity and sensitivity using the online database Web of Knowledge. The results of the scoping search were used to inform the final search strategy.

Wildcards (*) were used, where accepted by a database/search engine, to pick up multiple word endings. For example pollut* would pick up pollutant, pollution. Keywords were made more restrictive by the addition of a qualifier, or multiple qualifiers e.g. (slurry application AND pollut*AND water). The combination of qualifiers and keywords varied for each outcome studied based on the results of the scoping search. The exact keyword and qualifier combinations used for each of the database and web searches are listed in Table 1.

The following online sources were searched to identify relevant literature:

Electronic databases:

ISI Web of Knowledge involving the following products: ISI Web of Science; ISI Proceedings

Science Direct

Wiley Online Library

Index to Theses Online

CAB Abstracts

Organisational websites:

Defra online databases

Environment Agency

Natural Environment Research Council Open Research Archive

Centre for Ecology and Hydrology

Countryside Council for Wales

Scottish Environment Agency

Northern Ireland Environment Agency

Table 1. Search terms used for the REA

Search term	String 1		String 2		Limiting string 3		Limiting string 4
1	Timing	AND	slurry	AND	pollut*		
2	Timing	AND	slurry	AND	pollut*	AND	water
3	Timing	AND	slurry	AND	nitrate*		
4	Timing	AND	slurry	AND	pathogen*		
5	Timing	AND	slurry	AND	ammoni*	AND	water
6	Timing	AND	slurry	AND	ammonia volatilization		
7	Timing	AND	slurry	AND	phosph*	AND	water
8	Timing	AND	slurry	AND	leach*	AND	water
9	Slurry appl*	AND	pollut*				
10	Slurry appl*	AND	nitrate*	AND	pollut*		
11	Slurry appl*	AND	pathogen*				
12	Slurry appl*	AND	ammoni*	AND	pollut*		
13	Slurry appl*	AND	ammoni*	AND	water		
14	Slurry appl*	AND	ammonia volatilization				
15	Slurry appl*	AND	phosph*	AND	water		
16	Slurry appl*	AND	leach*	AND	water		
17	Timing	AND	slurry	AND	nitrate*	AND	water
18	Timing	AND	slurry	AND	pathogen*	AND	water
19	Timing	AND	slurry	AND	ammonia volatilization	AND	water
20	Slurry appl*	AND	pollut*	AND	water		
21	Slurry appl*	AND	nitrate*	AND	water		
22	Slurry appl*	AND	pathogen*	AND	water		
23	Slurry appl*	AND	ammonia volatilization	AND	water		
24	Slurry appl*	AND	pollut*	AND	river		
25	Timing	AND	slurry	AND	pollut*	AND	River
26	Slurry appl*	AND	pollut*	AND	catchment		
27	Timing	AND	slurry	AND	pollut*	AND	catchment
28	Slurry appl*	AND	run off				
29	Timing	AND	slurry	AND	run off		

In addition, web searches were performed using the search engines http://google.com and http://scholar.google.com. The first 50 hits (.doc .txt.xls and .pdf documents where this could be separated) from each data source were examined for appropriate data. No further links from the captured website were followed.

Database and repository searches were conducted in the English language. The potential language bias associated with this strategy was discussed with funders, and was considered acceptable for this review.

The results of each search term on each database were imported into a separate EndNote X2TM library file. Once the searching process was complete, all the database libraries were incorporated into one library, and the number of references captured was recorded. Using the automatic function in the EndNote software any duplicates were removed.

A record of each search was made to enable a re-run of the search if necessary.

Date search conducted

Database name

Search term

Number of hits

Notes

Study inclusion criteria

All retrieved studies were assessed for relevance using inclusion criteria developed in collaboration with funders and with subject experts as follows:

Relevant subject(s): Studies that investigated at least one of the following aspects of water quality: nitrate, phosphate or bacterial pathogen levels, as an effect of alteration to the timing of slurry application were considered for inclusion, irrespective of scale. Stakeholders agreed that the study should focus on temperate countries with similar farming systems to the UK. Those countries were: UK, Ireland, France, Belgium, Switzerland, Germany, Holland, Luxembourg, Liechtenstein, Denmark, Sweden, Norway, Finland, Austria, Slovakia, Poland, Hungary, Czech Republic, Romania, Lithuania, Latvia, Estonia, Belarus, Ukraine, northern states of the USA, Canada and New Zealand.

Language: Studies published in English.

Date: No date restrictions were applied.

Types of comparator included: Variations in timing of slurry application. Studies that compared or observed effects before and after the implementation of the intervention were also included.

Types of outcome: Differences in water quality measured as change in levels of nitrate, phosphate and bacterial counts were considered.

Types of study: Any experimental or correlative research study that collected primary data to investigate the effectiveness of varying the timing of slurry application for delivering an improved water environment were considered.

Evidence refinement

The first stage of evidence refinement involved the application of the inclusion criteria in the study of each article using only the title/abstract or headline/first paragraph. If there was any uncertainty or where there was insufficient information to make an informed decision regarding a studies inclusion, then relevance to the next stage of the review process (full text assessment) was assumed. The refined list of search results went forward for use in the REA and the number of references excluded was recorded. The inclusion criteria were applied by one reviewer to all potential articles, except where there was any uncertainty, where a second reviewer examined the texts and a consensus agreement was made.

Data extraction strategy

Database

Studies that passed the inclusion criteria were imported into a database. Each article was coded and categorised using a combination of generic (e.g. country/s of study, publication date, length of study etc.) and topic specific (e.g. application timings studied) keywords. Data regarding the study characteristics, quality of design and results were recorded. A notes section was used to identify any interesting or unexpected results, but this information was not included in further. Where there was more than one article found for a study, each article was recorded and cross referenced in the database.

The database was used to describe the extent of the research in the field and identify knowledge gaps. It is searchable by topic and can be arranged according to topic areas, publication date, pollutant type, country of study etc. Simple numerical accounts of the frequencies in each category can be obtained from the systematic map.

Subject experts reviewed the completed map to ensure that all relevant categories had been defined.

Quality assessment

Studies were assessed for the robustness of the study design in order to provide an indication of the overall quality of the research evidence. The values assigned to each study are based on the system outlined in Table 2.

Table 2- Scoring system used to provide a comparative value for study design

Category	Score	Hierarchy of evidence
Randomized	1	Yes - Randomized (includes partial)
	0	Not Randomized
Control	3	Controlled BACI
	2	Control
	1	Comparator
	0	None
Study length	1	Study length greater than or equal to a year
	0	Study length less than a year
Replicates	2	Replicate temporal (includes time series) and spatial
	1	Replicate temporal or spatial
	0	No replicates
Study type	3	Manipulative study
	2	Correlative study
	1	Monitoring study
	0	Sampling study

Adapted from: Donnison et al (2013)

No studies were excluded on the basis of study quality, but were categorised accordingly.

Data synthesis and presentation

Summary tables of study characteristics, study quality and results have been presented, accompanied by a narrative synthesis.

Where either quantitative or qualitative information on the effectiveness of varying slurry application timings was available for the studies assessed, the intervention was given a value for its effectiveness according to the system in Table 3.

Table 3. Scoring system used to assess mitigation effectiveness calculated from values in map

Category	Measure of effectiveness
2	Yes reduced -All forms of a measurement were reduced by the mitigation. OR Pollutant leakage not detected for any forms of measurement
1	Not clear – Outcome not clear as stated by authors, or not clear as mixed outcome for forms of measurement (No and not clear) OR Pollutant leakage outcome not clear.
0	No – No forms of a measurement were reduced by the mitigation. OR Pollutant leakage detected for all forms of measurement

Adapted from Donnison et al (2013)

Results and discussion

Initial searches identified 7,903 potentially relevant articles. Studies that did not directly address the question were removed through various stages of elimination, using keywords to exclude irrelevant topics or the screening of titles and abstracts for relevant information, leaving 34 relevant studies (Figure 1). These were placed in a database, which is searchable by topic. The database field and records are summarised in Appendix 1.

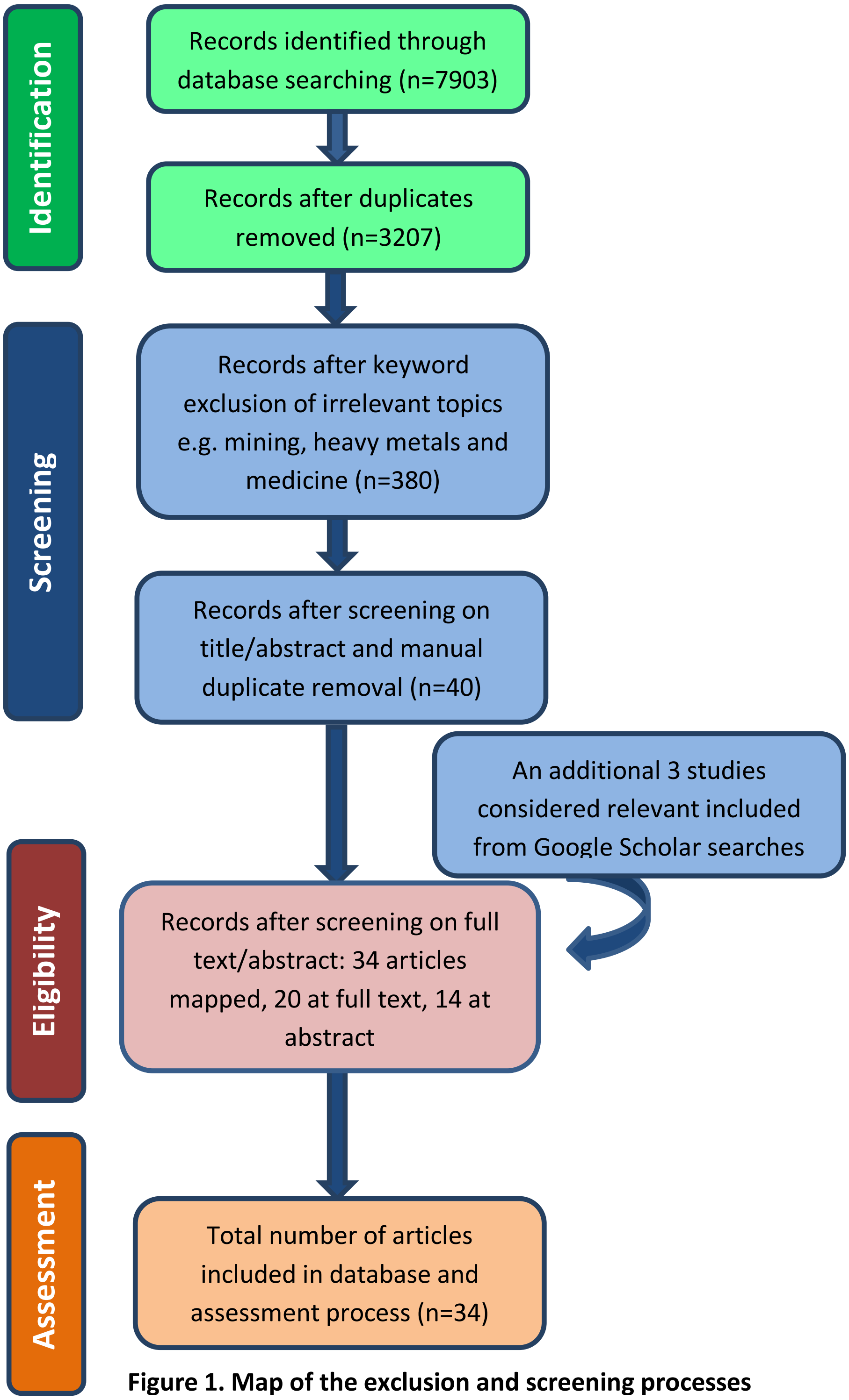

Figure 1. Map of the exclusion and screening processes

Reference type

Of the 34 studies identified as relevant to this REA, the majority were journal articles (24), with a further eight conference proceedings and two book references.

Available at full text

Only 20 of the 34 studies included in the database were available at full text level. Of the unavailable references (n=14), 6 were not available at full text level in the English language, and a further 5 conference proceedings, 1 book and 2 journal articles could not be obtained at full text during the study period. This lack of availability of a large number of relevant articles created some difficulties for further analysis and scoring of references.

Year of study

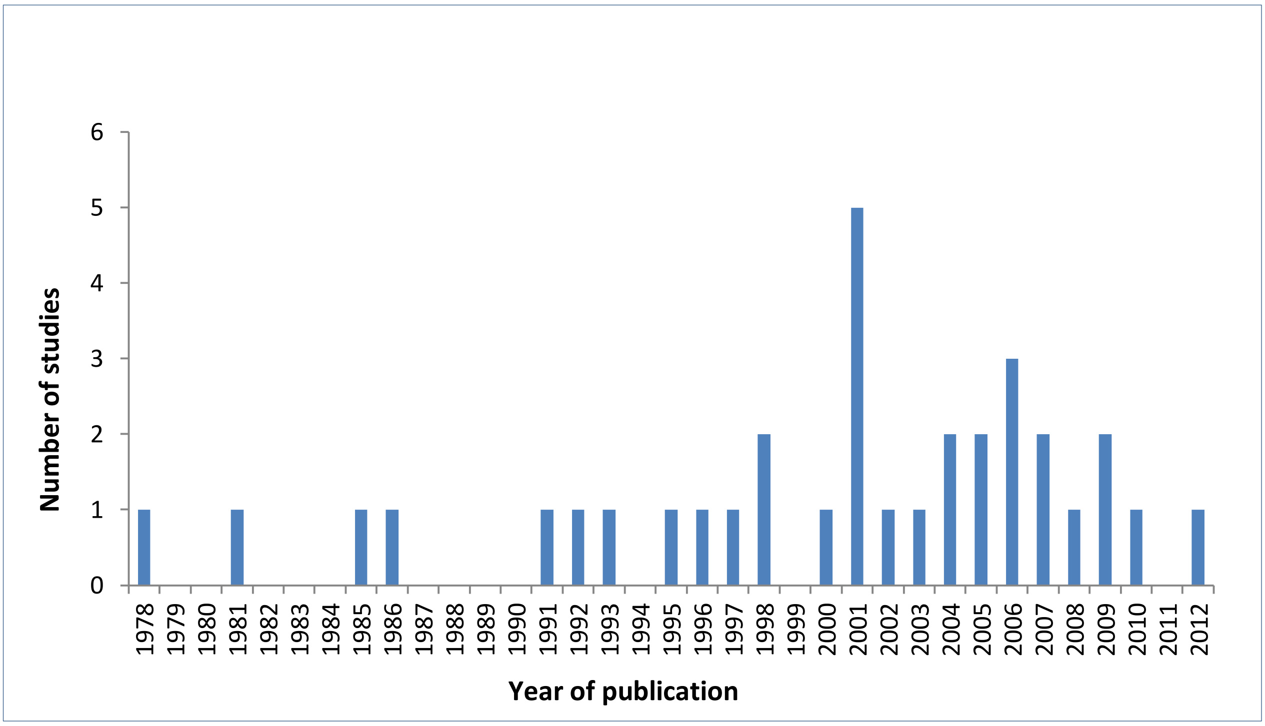

Figure 2. Distribution by year of articles included in the database

Figure 2 shows the distribution of research produced on the effects of the alteration of slurry application timing on elements of water pollution. Numbers of study per year were low, with no more than 1 per year between 1978 and 1997, with the frequency of study slightly increased between 1998 and 2012. Figure 2 also indicates that the majority of research in the area was carried out before 2008, when regulations regarding slurry application timing, as part of the NVZ regulations, were introduced.

Country of study

Figure 3 shows the distribution of country of study of the 34 studies included in the database. This figure indicates that the UK has been the dominant country producing 10 of the 34 relevant studies regarding the effects of this intervention on the assessed elements of water pollution. This dominance may also be influenced by the English language bias in the search and inclusion strategies. Six studies did not communicate information on the country of study, but all of these studies were only available at abstract level.

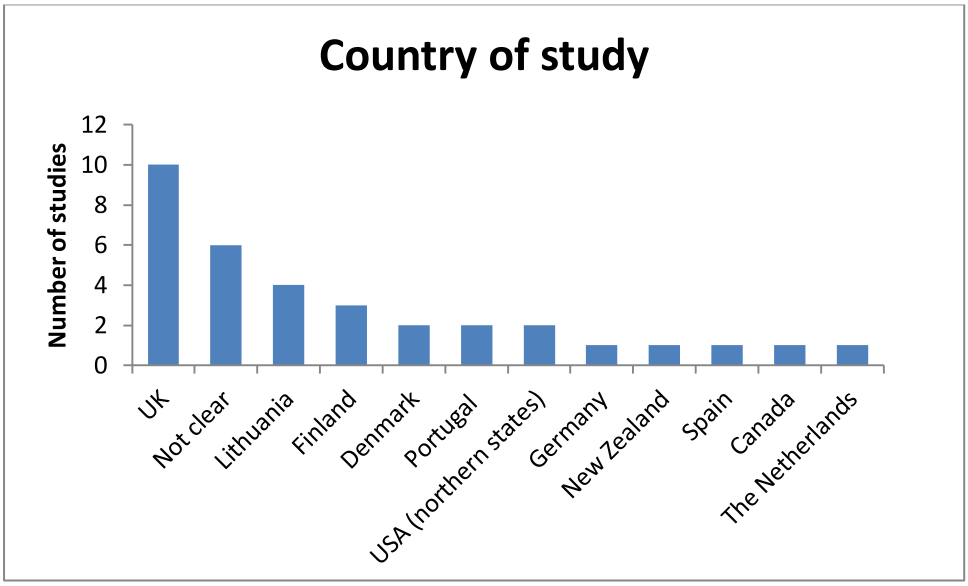

Figure 3 – Distribution of country of study

Intervention studied

Studies were carried out across all four seasons and usually compared one or more seasons or months of application, but reporting was variable. Some authors reported the timing of application in months and others in seasons sometimes without specifying how months were classified into seasons. Where it was not specified we categorised seasons as follows: Spring - March to May, Summer - June to August, Autumn - September to October, and Winter – December to February. Using this as a general guide, autumn and spring applications were the most commonly studied seasons, with winter applications also being studied in approximately half of studies. Studies that included summer applications were less frequent.

Figure 4a demonstrates that the alteration of slurry application timing alone was not the most frequently studied intervention by a considerable margin. Alteration of timing was more frequently combined with additional interventions which are detailed in Fig 4b. The inclusion of an additional intervention or the inclusion of the alteration of slurry application rate was investigated in 26 of the 34 studies included in the database.

The study of the alteration of both slurry application timing and rate was as frequently investigated as timing alone, with timing and timing and rate combined both being the intervention of focus in 7 studies.

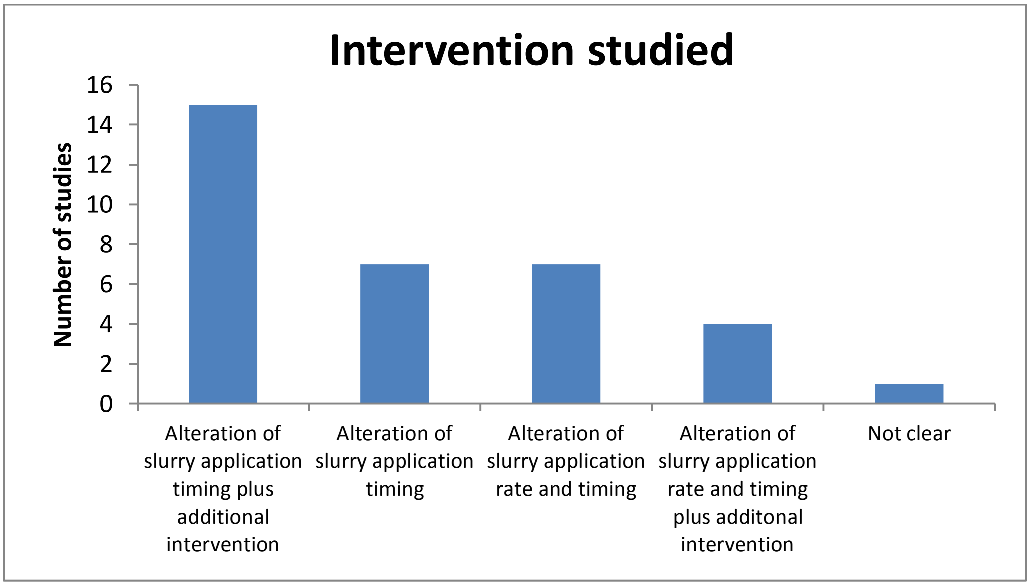

Figure 4a – Distribution of interventions studied

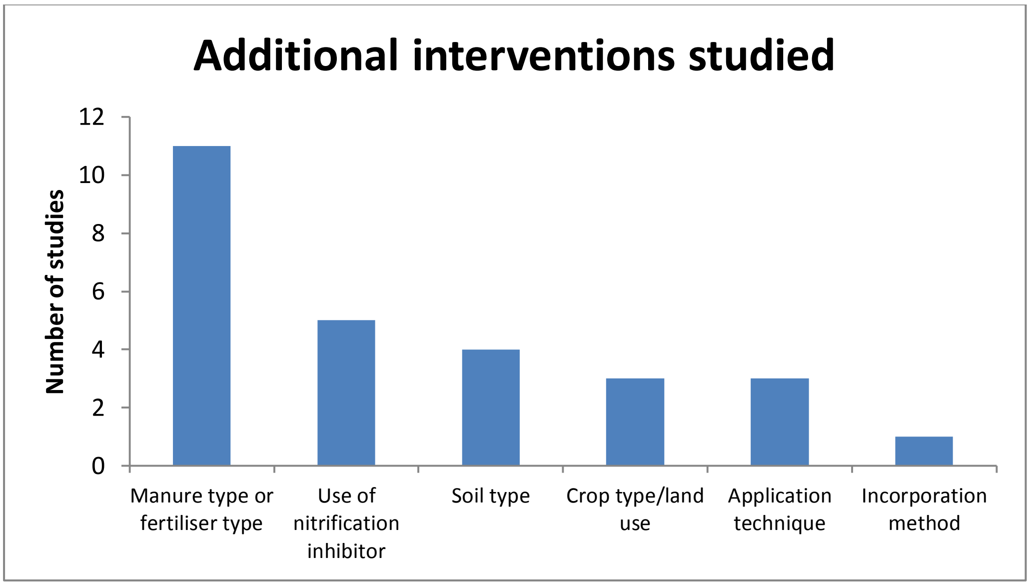

Figure 4b – Distribution of additional interventions studied alongside timing of slurry application timing

This inclusion of additional interventions in a study can often make results difficult to interpret, with 10 of the 20 full text studies (50%) having to be excluded from scoring for effectiveness and hierarchy of evidence due to confounding factors (where it was not possible to tell which intervention impacted on the outcome, either due to study design or to poor reporting). This issue requires further thought in future research. Where more than one intervention is studied, testing of each intervention independently would minimise the occurrence of confounding factors, and so facilitate clearer conclusions and enable cause and effect relationship to be more easily established.

Study length

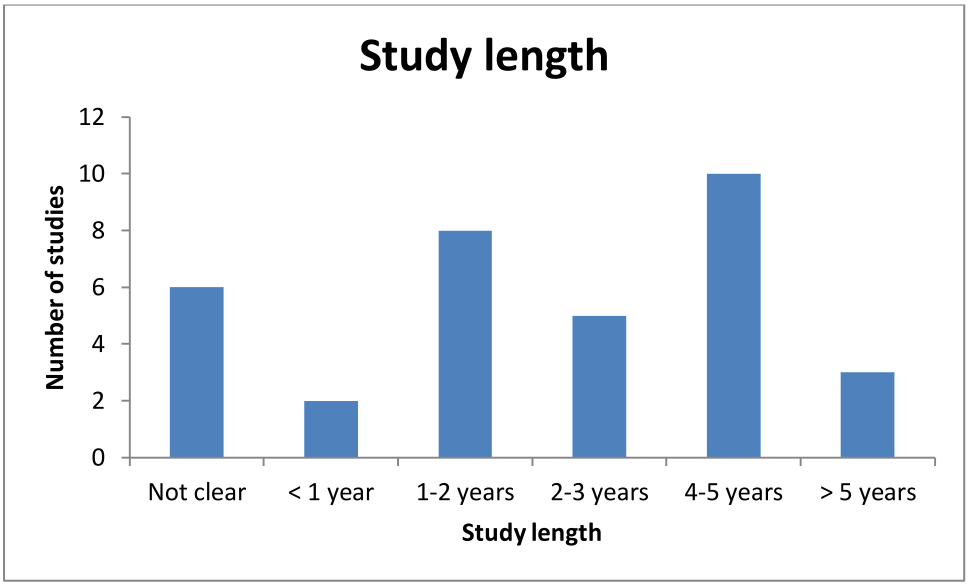

Figure 5 – Study design: study length

Figure 5 illustrates the variation in study lengths used in the 34 studies included in the database. 76% of studies were carried out over a period of one year or more with 38% of these studies being carried out over a period of 4 years or more.

Outcome comparator

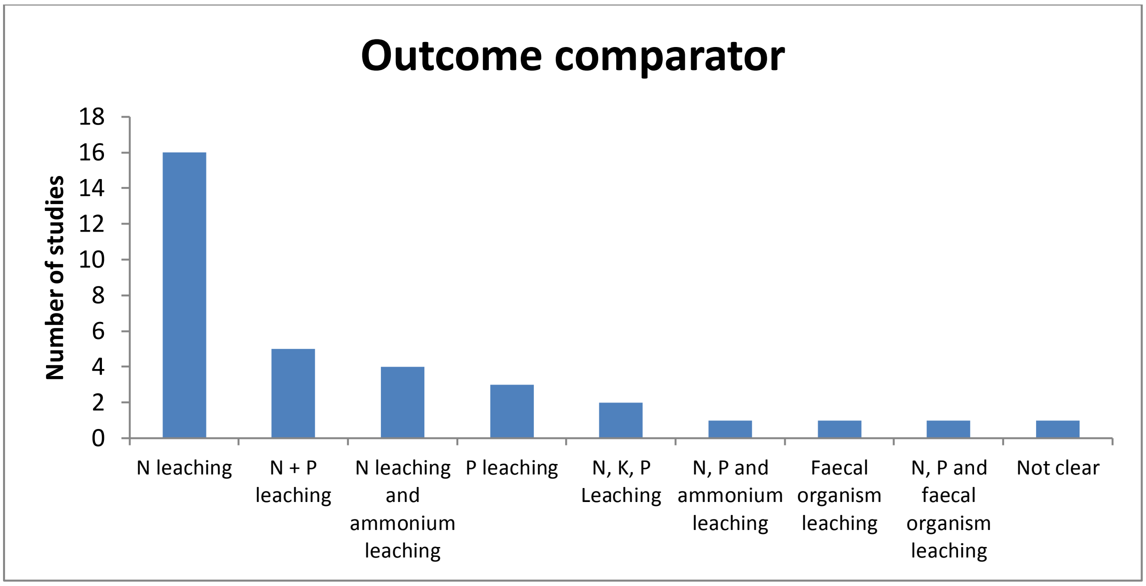

Figure 6 – Distribution of outcome comparators studied

N leaching was the most frequently studied outcome comparator by a considerable margin, with 16 of the 34 studies investigating the impacts of the alteration of slurry application timing on N leaching (Figure 6). Very little variation was observed in the number of studies produced for the remaining comparators. Only two studies investigated the effects of the intervention on the leaching of faecal indicator organisms (FIOs), highlighting a potential research gap with N, P and FIO's all forming important components of water pollution. These findings indicate a potential over-emphasis on the study of N leaching in comparison to other important outcome comparators.

Of the studies that assess multiple pollutant outcomes (n=12), a considerable proportion of these studies (n=7) either displayed unclear results or variable outcomes for the different pollutants studied making overall conclusions particularly difficult to determine. This finding indicates the importance in clear reporting of results in order for successful wider interpretation.

Study type

Over 60% of the 34 studies included in the database had a manipulative study design (Figure 7). For 11 studies, the study design was unclear, but all of these 11 were obtained at abstract only.

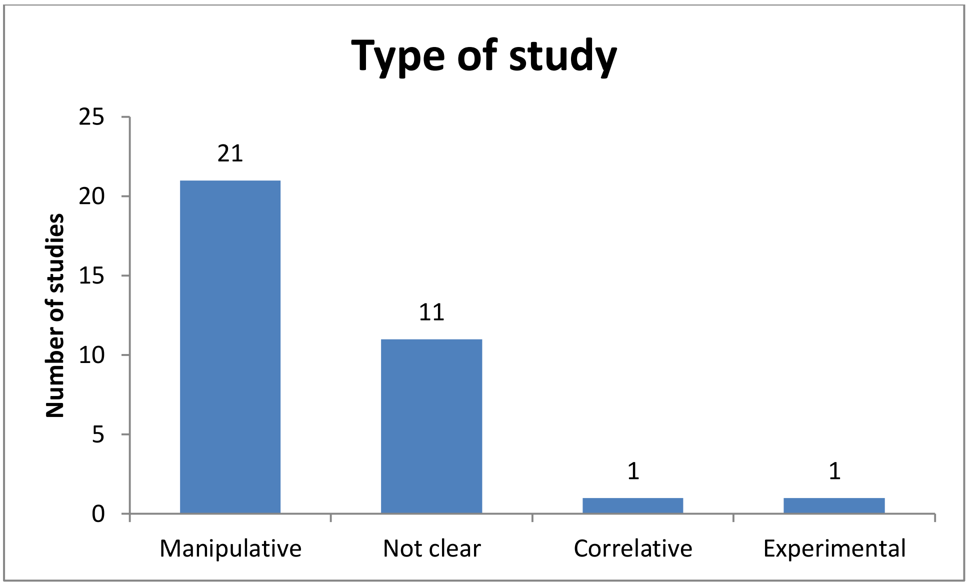

Figure 7 – Number of articles reporting different types of study design

Control

Figure 8 demonstrates that 38% of articles (n=13) included in the database reported using a control, with 44% (n=15) using a comparator and the remaining 18% of studies either using no control or unclear (all of the articles categorised as unclear were only available at abstract level).

No studies appeared to follow a BACI design, highlighting a potential research need to rigorously assess the impact and effectiveness of the implementation of the NVZ regulations regarding slurry application timing.

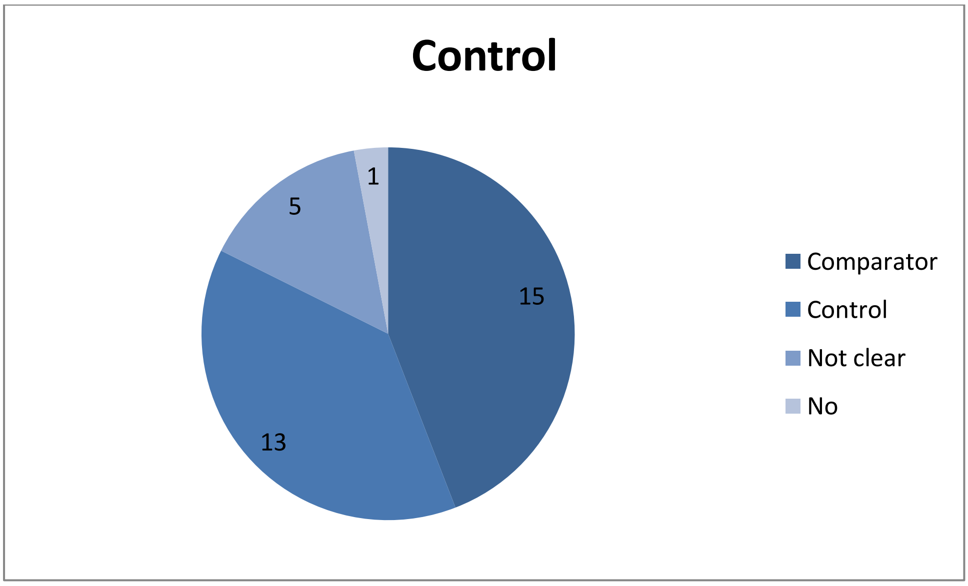

Figure 8 – Number of articles reporting use of a control or comparator. All full text articles reported presence or absence of controls and comparators. Those where 'not clear' is reported were all obtained at abstract only.

Randomization and replication

The presence of randomisation and replication was an important part of the hierarchy of evidence scoring. Nine of the 20 full text studies reported randomisation, (for the 11 that did not, it was assumed that randomisation did not take place), but replication was more common, with over half of the 20 full text articles reporting both spatial and temporal replicates. A further 6 reported spatial replicates only, and 2 reported temporal replicates only (Figure 9).

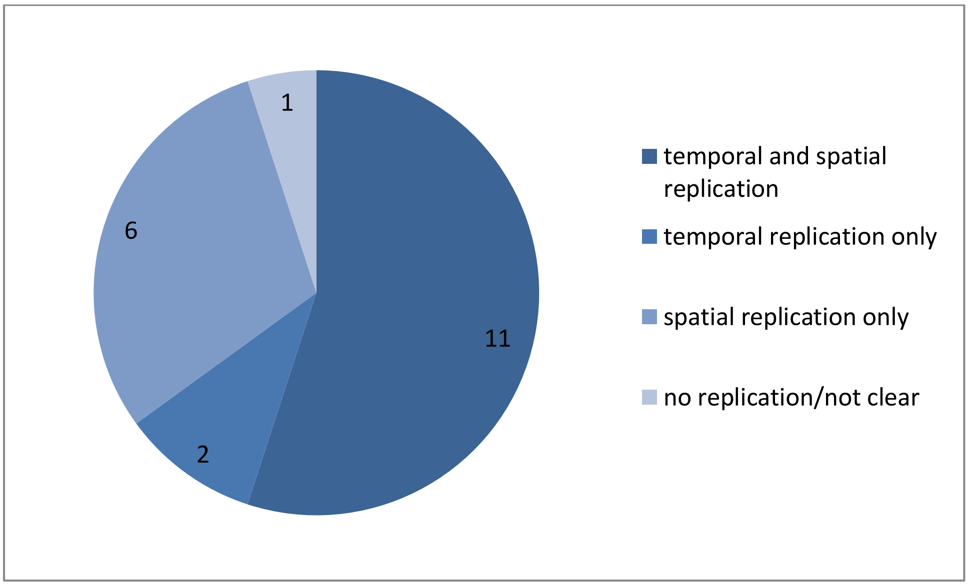

Figure 9 – Number of full text articles reporting use of replication in study design

Soil type

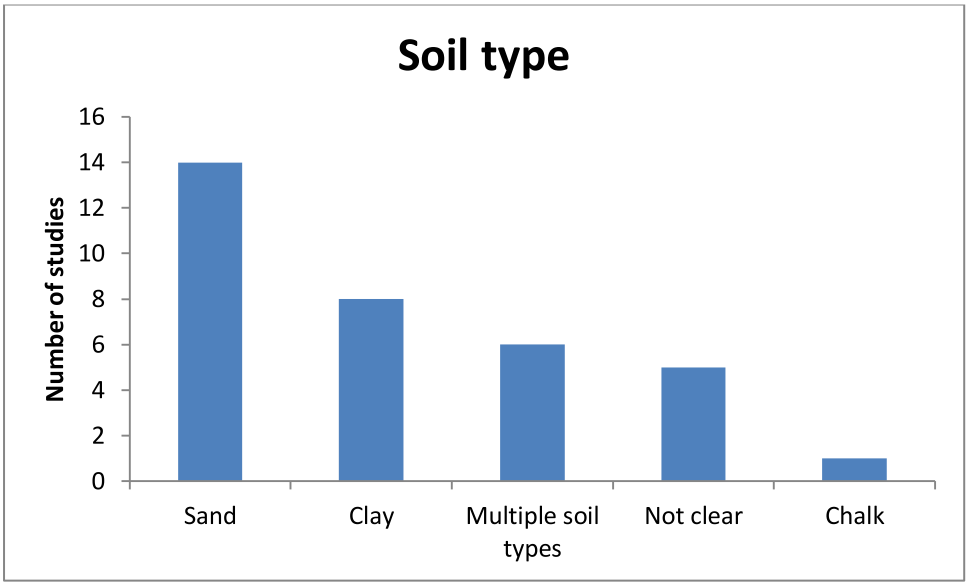

Figure 10 – Soil types studied

Information on the soil type studied was frequently available (85% of the articles included in the database, see Figure 10). No obvious relationship has been observed between soil type and the effectiveness of the alteration of slurry application timing on minimising elements of water pollution.

Quality and effectiveness assessment

Of the 34 studies included in the database, only 8 were scored for both robustness of evidence and for the effectiveness of intervention. The remaining 24 studies were excluded due to poor reporting, confounding factors, or the lack of availability of studies at the full-text level. The scores are summarised in tables 4 and 5. Half of the included studies (n=4) had a value of 9 (from a maximum of 10) for study design, and the remaining had values ranging from 6 to 8, indicating that the evidence is likely to be fairly robust based on the generic indicators used.

Seven of the 8 studies found that the variation to timing of slurry spreading interventions were effective. The details of the interventions used and the best and worst times are summarised in Table 5.

Table 4. Combined hierarchy of evidence and effectiveness scores for 8 studies investigating the impact of varying the timing of slurry applications on water pollution.

	HIERARCHY OF EVIDENCE VALUE						
Study id no/1st author	STUDY LENGTH	STUDY TYPE	CONTROL	RANDOMIZATION	REPLICATES	**TOTAL**	VALUE FOR EFFECTIVENESS OF INTERVENTION
3/Beckwith, C. P.	1	3	2	1	2	**9**	**2**
8/Estavillo, J. M.	1	3	2	1	2	**9**	**0**
9/Froment, M. A.	0	3	2	1	2	**8**	**2**
12/Jayasundara	1	3	2	1	2	**9**	**2**
21/Smith, K. A. 2002	1	3	2	1	2	**9**	**2**
23/Smith, K. A. 2001b	1	3	1	1	1	**7**	**2**
25/Thomsen, I. K.	1	3	1	0	1	6	**2**
31/Harold, M. van Es	1	3	1	0	2	7	**2**
			MAX. POSSIBLE VALUE			**10**	**2**
			MEAN			**8.00**	**1.75**
			SD			**1.20**	**0.71**

Table 5. The best and worst times for application of slurry as reported by authors of 8 studies tested for robustness of evidence and effectiveness of intervention, using full text studies with no confounding factors.

Reference ID		spring			summer			autumn			winter		Leachate measured	Effectiveness value (out of 2)	Hierarchy of evidence value (out of 10)
	March	April	May	June	July	August	Septembe	October	November	December	January	February			
3													N	**	*********
8		no significant differences for leaching using 4 application timings											N		*********
9													N	**	********
12													N	**	*********
21													N, ammonium	**	*********
23		split application November/March better than November alone.							...				P	**	*******
25													N	**	******
31							...Worst time for N loss on arable			...Worst time for P loss on grass			N	**	*******

Unclear result

Least leaching occurred

Most leaching occurred

....
Most leaching occurred but clarification provided in table

Best timing for slurry application – general trends

Table 5 shows the 8 full text studies, without confounding factors that were given values for robustness of the evidence, and for effectiveness of the interventions. Seven of the 8 authors for studies included in the assessment indicated that the worst leaching (mainly of N) occurred in after autumn slurry applications, with least leaching occurring in winter or spring (with one exception, where P losses on grass appeared to be worst following winter applications). In very general terms this pattern was supported by the other studies in the database, where spring was the season most often identified as the best timing for slurry application in terms of pollution reduction or mitigation (11 of the 34 included articles). However, a variable or unclear best application timing result was more frequently recorded (n=14). Again, in very general terms, autumn was the season most commonly identified as the worst period for slurry application (n=15). It is important to note that a variable or unclear worst application timing result was also frequently recorded (n=13). However, analysing the best/worst timings for slurry application in isolation can produce misleading trends due the large variation in timings studied. Some of the studies included in the database as a whole were only read at abstract or had confounding factors.

Summer applications were less frequently studied than applications in other seasons and of the three studies found at full text and without confounding factors that included summer applications (table 5) two did not report any clear differences between slurry applications in summer and in other seasons.

Summer applications were less frequently studied than applications in other seasons and only one study was found at full text and without confounding factors

Autumn application versus spring application

Of the studies comparing the impacts of autumn and spring slurry application (n=6), spring application was most frequently found to be the season of lowest pollution in terms of N and P (4 of the 6 studies). A further 2 studies demonstrated unclear or variable results in terms of the best timing for application. With regard to the worst timing of application, autumn was found to be the worst season for N and P pollution as a result of slurry application (5 of the 6 studies), with the findings unclear from the remaining study, but again some of the included studies had confounding factors or were only read at abstract.

Autumn application versus winter application

Of the studies comparing the impacts of autumn and winter slurry application (n=4), the leaching of N was found to be reduced under winter application in all of the studies, with autumn identified as the worst application timing in terms of leaching of N (3 studies demonstrated an increase in N leaching compared to winter application, with the results of one further study unclear).

Autumn application v winter application v spring application

Of the studies comparing the impacts of autumn, winter and spring slurry application (n=5), the leaching of N and P was studied in 3 studies, and all produced variable and or unclear results for the best timing of application. The leaching of N was studied in 2 studies, one of which suggested that spring was the best application time and the other suggesting that winter or spring application lead to reductions in N leaching. In terms of the worst timing for slurry application, autumn was suggested to be the worst timing for slurry application for N leaching in 3 of the 5 studies. P leaching was greatest after winter application as suggested by 1 study, and autumn and winter were both quoted as the seasons for highest P and N leaching following slurry application in one study.

Split applications

The effect of splitting slurry applications between multiple seasons was investigated alongside single applications at either spring or autumn in 8 studies. Of these, splitting applications between autumn and spring (n=2) or single spring applications (n=3) appeared to be most effective in reducing leaching of both N and P, with the findings of the remaining 3 studies unclear. The worst leaching of N P and/or FIOs was following a single autumn application (n=5) with the findings of the remaining 3 studies unclear.

It is important to highlight that the analysis of the best and worst timing for slurry application as detailed by the 34 studies included in the database does not include or compare all of the timings studied. The large variation in timings studies, together with confounding factors made it particularly difficult to generate comparisons.

Comparing the impact of alteration of timing on different pollution outcomes

It is important to determine whether the general trends in best and worst slurry application timing were consistent between the various outcome comparators assessed. Of the 13 studies which investigated P leaching and/or FIO leaching as at least one of the pollutant measurements conducted, no considerable or obvious deviation from the general trends in best and worst timing for slurry application was observed. However, one study (Turtola 1998) recorded high P leaching rates following spring slurry application but also observed high leaching of both N and P following autumn and winter application.

Percentage reductions of pollutants

Of the 34 studies included in the database, only 5 described percentage reductions in the pollutants studied as a result of the alteration of slurry application timing. The figures reported for pollutant reduction ranges from 11.5% up to 42.8%, with an average pollutant reduction of 24.6% following spring slurry application (usually when compared with autumn). The extent of pollution reduction was variable between studies and between the pollutants studied. The greatest pollution reduction was observed for P leaching, with Miseviciene (2004) quoting a 42.8% reduction following spring slurry application (abstract only). Although only reported in a small proportion of studies (and many of these were not read at full text or had confounding factors), a mean pollutant reduction of 24.6% following spring slurry application demonstrates significant support for the application of slurry in the spring following winter storage.

Conclusions

Key findings

The collation of evidence in this database has allowed the effectiveness of the alteration of slurry application timing as in intervention for delivering an improved water environment to be assessed.

General trends in the data assessed demonstrate that application of slurry in spring leads to lower losses of the pollutants, N, P and FIOs as a result of leaching following application, suggesting that spring is the best season for slurry application, although winter was also frequently found to be preferable to autumn. Autumn application consistently led to higher levels of pollutant leaching, suggesting that autumn is the worst season for slurry application, producing the greatest pollution impact.

The data collated also demonstrates no obvious deviation from these general trends in best and worst slurry application timings when a range of different pollutant outcome comparators and soil types were studied.

Implications for policy and practice

The majority of available research demonstrated that autumn application poses the most significant risks in terms of nutrient and pollutant leaching providing support for current NVZ regulations, as part of the wider WFD policy, which prevents slurry application during the autumn and early winter period. In terms of translation to farming practice, this finding also supports the practice of secure slurry storage through the autumn and winter period for application to land to take place in the following spring.

These findings would broadly support current NVZ restrictions on slurry application up until 31st December or 15th January (depending on soil type). However, the leaching of nutrients and pollutants was also frequently cited to be reduced following winter slurry application, when compared with autumn but there were few comparisons between winter and spring, and this evidence would be useful in order to further inform regulations. Although, it is worth noting that even if demonstrated to be one of the best timings, in terms of farming practice winter application is likely to be regularly unfeasible, with water logged soils creating difficultly for using heavy spreading machinery and the greater risk of weather conditions such as frozen soils or heavy rains leading to the failure to comply with other aspects of the NVZ slurry application regulations. These risks therefore add further support to the conclusion that spring is the best season for slurry, both in terms of farming practice and the associated water pollution impacts.

Implications for research

Although this REA demonstrates that there is a considerable amount of research available on the effectiveness of this intervention, a number of areas where research and scientific evidence is currently lacking have been highlighted.

The research found was dominated by the study of the effect of this intervention on the leaching of N. The number of studies assessing the impact of the alteration of slurry application on P and FIO pollution was considerably smaller, highlighting a potential research gap as both P and FIOs also have the potential to cause significant environmental and human health impacts, although a separate evidence review (Donnison et al 2013) found that FIOs reduce during slurry storage.

Studies comparing the effects of application throughout the year at each of the four seasons are lacking. Although the vast majority of studies were carried out over a period of more than one year, there was a considerable lack of research covering and comparing all four seasons. In particular, it would be useful to compare winter and spring slurry applications.

The quality of evidence included in this REA was highly variable. Less than a third of studies were able to be taken through to the scoring procedures due to issues with poor reporting, confounding factors or a lack of availability of references at full-text. In future, the encouragement of more accurate reporting of key features of study design such as randomization and replication would allow more detailed assessment of study quality. Future studies should also report reductions quantitatively (e.g. percentage reduction) for increased value.

The study of the alteration of slurry application timing in isolation, as opposed to the combination of multiple interventions i.e. application timing and rate, would prove more effective, reducing the potential impact of confounding factors and allowing more accurate conclusions to be drawn from research. Alternatively, clearer reporting of the results for each intervention studied should be encouraged.

The lack of BACI designed studies conducted on this topic as demonstrated by this REA, is also identified as a potential research gap to be investigated in future. Studies of this design would provide a more accurate assessment of the effectiveness of this intervention, also with the potential to assess the effectiveness of the introduction of relevant policy i.e. NVZ regulations.

Although no obvious relationship was observed between the effectiveness of the alteration of slurry application timing and soil type as part of this REA, the NVZs' restrictions regarding closed periods for slurry application are directly linked to soil type. Further research in this area would help to establish if there is any link between best/worst slurry application timing and soil type, and whether this variation in the NVZs' restrictions is warranted.

Acknowledgements and competing interests

The authors have funded by the Natural Environment Research Council. The work was commissioned by the Department of Environment Food and Rural Affairs. Thanks to Paul Lewis, Deborah Coughlin and Stuart Kirk for their advice and comments on this work. Whilst we consider that this work has been carried out in accordance with good industry practice, the University will not be liable for any use which may be made, reliance which may be placed, nor advice or information given, in connection with the results contained herein for commercial purposes.

References

Chambers, B. J., K. A. Smith*, et al*. (2000). Strategies to encourage better use of nitrogen in animal manures. *Soil Use and Management* 16: 157-161.

Collins, A. L., *et al.* (2009). Predicting potential change in agricultural sediment inputs to rivers across England and Wales by 2015. *Marine and Freshwater Research* 2009, 60:626-637.

Defra. (2009). *Protecting our Water, Soil and Air: A Code of Good Agricultural Practice for farmers, growers and land managers*. [Online] Available from: http://adlib.everysite.co.uk/resources/000/252/413/water_air_soil_code_2009.pdf [Accessed on 17/4/13].

Defra. (2011). *Water for Life White Paper*. UK: Department for Environment, Food and Rural Affairs.

Defra. (2012*a*). *Catchment Sensitive Farming*. [Online] Available from: https://www.gov.uk/catchment-sensitive-farming#water-pollution-from-farming-and-how-to-reduce-it [Accessed on 17/4/13].

Defra. (2012*b). Nitrate Vulnerable Zones*. [Online] Available from: https://www.gov.uk/nitrate-vulnerable-zones#how-to-comply-with-nvz-rules [Accessed on 17/4/13].

Defra. (2013). *Nitrates Directive. Q and A on Nitrates Regulations Effective 17th May 2013*. Department for Environment Food and Rural Affairs.

Donnison L.M., Lewis P.J., Smith B, and Randall N.P., (2013). *How effective are slurry storage, cover or catch crops, woodland creation, controlled trafficking or break-up of compacted layers, and buffer strips as on-farm mitigation measures for delivering an improved water environment. WT0965 Draft Report* (Department for Environment Food and Rural Affairs

Edwards, A., Withers, P. (2008). Transport and delivery of suspended solids, nitrogen and phosphorus from various sources to freshwaters in the UK. *Journal of Hydrology,* 350: 144-153.

European Commission. (2010). *The EU Nitrates Directive*. [Online] Available from: http://ec.europa.eu/environment/pubs/pdf/factsheets/nitrates.pdf [Accessed on 17/4/13].

Kay, D. *et al.* (2008). Quantification and control of microbial pollution from agriculture: a new policy challenge? *Environmental Science & Policy,* 11: 171-184.

Milar J, Coughlin D and Kirk S (2012) Guidance Document for the production of Quick Scoping Reviews and Rapid Evidence Assessments (Beta Version 8). Department for Environment Food and Rural Affairs

Misevičiene, S. (2004). Environmental evaluation of slurry applied on fields. / Trešimo skystuoju mešlu gamtosauginis vertinimas. *Water Management Engineering* 26(46): 12-18.

Natural England. (2013). *Water Framework Directive*. [Online] Available from: http://www.naturalengland.org.uk/ourwork/water/waterdirective.aspx [Accessed on 17/4/13].

Nicholson, F., *et al.* (2011). *Pollutant losses following organic manure applications in the month following the end of the closed period*. Report for Defra project: WT0932 [Online] Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/82413/20111220nitrates-directive-consult-evid6.pdf [Accessed on 17/4/13].

Turtola, E. (1998) "Nitrogen and phosphorus losses in surface run off and drainage water after application of slurry and mineral fertilizer to perennial grass ley." *Agricultural and Food Science in Finland*. 7: 569-581

Williams, J. (2006). Strategies to reduce diffuse nitrogen pollution from cattle slurry applications. DIAS Report, *12th Ramiran International conference, Technology for Recycling of Manure and Organic Residues in a Whole-Farm Perspective*. Vol. I [Online] Available from: http://www.ramiran.net/doc06/djfma122.pdf [Accessed on 17/4/13].

Appendix 1. Summaru of 34 articles that present research into the impact of alteration of slurry timing on leaching of nitrates, phosphates and/or faecal indicator organisms.

ID	1sr author	year	reference	ref type	text read	linked study	intervention	country study	years of study	study type	control?	comparator	randomized	spatial replicate	temporal replicate	study scale	Location & method	soil type	measurements conducted	timings studied	best timing	worst timing	redution?	N reduced	P reduced	fio reduced	comments on pollutant	confounding	reasons for heterogeneity
1	Aškinis, S.	2001	Aškinis, S., M. Čizauskiene, et al. (2001). "Nutritious matter leaching from the rotation fields applied with slurry." Vandens Ukio Inzinerija 14(36): 7-17.	Jnl	Abst		Alteration of slurry application timing	Lithuania	4	Not clear	spring v autumn v 1/2 spring 1/2	NKP leaching	Not clear	Not clear	Not clear	Not clear	Not clear	Sandy loam	N,K,P, biogenic matter, soil pressing	Spring v autumn v half spring half	Spring	Autumn	Yes				In spring		Different crop types grown in each study
2	Aškinis, S.	2003	Aškinis, S. and S. Misevičiene (2003). "Investigations on phosphorus leaching in crop rotation fields when slurry is applied. Vandens Ukio Inzinerija 22(44(1)): 58-66.	Jnl	Abst		Alteration of slurry application timing	Not clear	4	Not clear	spring v autumn v half spring half	Phosphate leaching	Not clear	Not clear	Not clear	Not clear	Not clear	Not clear	P leaching	Spring v autumn v half spring half	Spring	Autumn	Yes		yes		In spring		
3	Beckwith, C. P.	1998	Beckwith, C. P., J. Cooper, et al. (1998). "Nitrate leaching loss following application of organic manures to sandy soils in arable cropping. I." Soil Use and Management 14(3): 123-130.	Jnl	Full text		Manure type, alteration of slurry application timing	UK	4	Manipulative	no manure	Nitrate leaching	Yes	Yes	Yes	Multi-Site	Plot, Ceramic cup	Sandy loam, medium loam	N leaching, soil mineral N, crop	Monthly applications Sept -	Dec - Jan	Sep - Nov	Yes	yes			application in autumn & winter sig		
4	Bouwer, W.	1991	Mitteilungen der Deutschen Bodenkundlichen Gesellschaft 66(2): 919-922.	Jnl	Abst		Not clear	Germany	4	Not clear	Not clear	Nitrate leaching	Not clear	Not clear	Not clear	Not clear	Well	Podzols, gley-podzols and gleys	N leaching	Not clear	Not clear		Not clear	not clear					
5	Cameron, K. C.	2004	Cameron, K. C. and H. J. Di (2004). "Nitrogen leaching losses from different forms and rates of farm effluent applied to a Templeton soil in Canterbury, New Zealand." New Zealand Journal of Agricultural Research 47(4): 429-437.	Jnl	Full text		Manure type, alteration of slurry application timing	New Zealand	Not clear	Manipulative	autumn v autumn/spring v 4 annual applications	Nitrate leaching	Not clear	No	Yes	Farm	Field, Lysimeter	Sandy loam	N leaching	Autumn v autumn and spring v 4 annual	2 annual applications (autumn & spring) and 4		Yes	yes			Splitting applications into 2 or 4 portions applied at	Rate and manure type	

ID	1sr author	year	reference	ref type	text read	linked study	intervention	country study	years of study	study type	control?	comparator	randomized	spatial replicate	temporal replicate	study scale	Location & method	soil type	measurements conducted	timings studied	best timing	worst timing	redcution?	N reduced	P reduced	fio reduced	comments on pollutant	confounding	reasons for heterogeneity
6	Chambers, B. J.	2000	Chambers, B. J., K. A. Smith, et al. (2000). "Strategies to encourage better use of nitrogen in animal manures." Soil Use and Management 16: 157-161.	Jnl	Full text	3	Manure type, alteration of slurry application timing	UK	Not clear	Manipulative	no manure	Nitrate leaching	Not clear	Not clear	Not clear	Multi-Site	Ceramic cup	Sandy and shallow, over chalk	N leaching	Monthly applications Sept -	Jan		Yes	yes					
7	Dijk, T. A. v.	1985	Dijk, T. A. v. (1985). Leaching of plant nutrients from arable land as affected by annual applications of cattle slurry. Report of an 8-year lysimeter experiment. Rapport, Instituut voor Bodemvruchtbaarheid: 61-61.	Book	Abst		Alteration of slurry application rate and timing	Not clear	8	Not clear	spring application v autumn application	Crop uptake of N, Crop yield, Nitrate leaching	Not clear	Not clear	Not clear	Not clear	Lysimeter	Sandy loam	N leaching, crop yield, crop uptake of N	Spring application v autumn application	Not clear		Not clear	not clear					
8	Estavillo, J. M.	1996	Estavillo, J. M., M. Rodriguez, et al. (1996). "Nitrogen losses by denitrification and leaching in grassland - The effect of cow slurry application." Fertilizer Research 43(1-3): 197-201.	Jnl	Full text	11	Alteration of slurry application rate and timing, fertilizer type	Spain	2	Manipulative	no manure or fertilizer	Denitrification losses, Nitrate leaching	Yes	Yes	Yes	Site	Acetylene inhibition technique, Ceramic cup	Clay loam	N leaching, denitrification	4 annual applications	No significant differences between	Spring and autumn are highest risk for	Not clear	not clear			No significant differences between		
9	Froment, M. A.	1992	Froment, M. A., A. G. Chalmers, et al. (1992). "Nitrate leaching from autumn and winter application of animal manures to grassland." Aspects of Applied Biology(30): 153-156.	Jnl	Full text		Manure type, alteration of slurry application timing	UK	<1 yr	Manipulative	no manure or fertilizer	Nitrate leaching	Yes	Yes	Yes	Multi-Site	Plot, Ceramic cup	Chalk	N leaching	Monthly applications Sept -	December, January	September, October, November	Yes	yes			N leaching reduced in December and		

ID	1sr author	year	reference	ref type	text read	linked study	intervention	country study	years of study	study type	control?	comparator	randomized	spatial replicate	temporal replicate	study scale	Location & method	soil type	measurements conducted	timings studied	best timing	worst timing	redcution?	N reduced	P reduced	fio reduced	comments on pollutant	confounding	reasons for heterogeneity
10	Helnonen-Tanski, H.	2001	Helnonen-Tanski, H. and J. Uusi-Kämppä (2001). "Runoff of faecal microorganisms and nutrients from perennial grass ley after application of slurry and mineral fertiliser." Water Science and Technology 43(12):	Jnl	Full text		Alteration of slurry application timing, Application techniqu	Finland	2	Manipulative	mineral fertilizer	Feacal organisms in runoff, Nitrate	Not clear	Yes	Yes	Site	Plot, Water drainage/Drain	Clay silty soil	N leaching, P leaching, faecal organisms in	Summer v summer and autumn v winter	Not clear	P,N runoff worst after autumn appl, autumn	Not clear					Application technique	Weather conditions rainfall, snowmelt, P
11	Hodgkinson, R. A.	2007	Hodgkinson, R. A., P. J. A. Withers, et al. (2007). Risk and mitigation of P losses following organic manure applications. Diffuse phosphorus loss: risk assessment, mitigation options and ecological effects in river basins.	Conf proc	Abst		Alteration of slurry application timing, Incorporation method	UK	Not clear	Experimental	multiple timings investigated	Phosphate leaching	Not clear	Yes	Not clear	Multi-Site	Not clear	Mulitple soil types	P leaching	Single application v mothly applications	Not clear	Autumn and winter applications	Not clear	not clear					Weather conditions
12	Jayasundara, S.	2010	Jayasundara, S., C. Wagner-Riddle, et al. "Transformations and losses of swine manure N-15 as affected by application timing at two contrasting sites." Canadian Journal of Soil Science 90(1): 55-73.	Jnl	Full text		Alteration of slurry application timing	Canada	2	Manipulative	no manure	Nitrate leaching and crop uptake	Yes	Yes	No	Multi-Site	Plot, Ceramic cup	Sandy loam and silty loam	N leaching and crop uptake	November, April, June	April and June (spring pre-plant and side	November	Yes	yes					Soil type, weather conditions
13	Kemppainen, E.	1995	Kemppainen, E. (1995). "LEACHING AND UPTAKE OF NITROGEN AND PHOSPHORUS FROM COW SLURRY AND FOX MANURE IN A LYSIMETER TRIAL." Agricultural Science in Finland 4(4): 363-375.	Jnl	Abst		Alteration of slurry application timing, Soil type, Use of a nitrific	Not clear	3	Not clear	Not clear	Nitrate leaching , phosphate leaching	Not clear	Not clear	Not clear	Not clear	Lysimeter	Peat and fine sandy soil	N leaching, P leaching, crop yield, crop uptake	Not clear	May		Yes	yes	not clear		May application reduced N leaching,		

14	Lewis, P.J.	1997	Lewis, P. J., C. P. Beckwith, et al. (1997). Effect of manure application timings and autumn/winter rainfall drainage patterns on nitrogen availability in cut grassland systems.	Conf proc	Full text	3,7	Alteration of slurry application rate and timing	UK	6	Manipulative	mineral fertilizer, Yes - no manure	Herbage production, Nitrate	Not clear	Not clear	Yes	Site	Ceramic cup	Sandy loam	N leaching, ammonium	Expt 1 -June, monthly	Spring		Not clear	not clear			N recovery increased	Rate	
15	Miseviciene, S.	2005	Miseviciene, S. (2005). Pollution of drainage water with nitrogen when slurry is applied in crop rotation fields.	Book	Abst		Alteration of slurry application timing	Lithuania	4	Not clear	spring application v autumn application	Nitrate leaching	Not clear	Not clear	Not clear	Not clear	Not clear	Not clear	N leaching	Spring v autumn	Spring	Autumn	Yes	yes			Spring application reduced N leaching		
ID	1sr author	year	reference	ref type	text read	linked study	intervention	country study	years of study	study type	control?	comparator	randomized	spatial replicate	temporal replicate	study scale	Location & method	soil type	measurement s conducted	timings studied	best timing	worst timing	redution?	N reduced	P reduced	fio reduced	comments on pollutant	confounding	reasons for heterogeneity
16	Miseviciene, S.	2004	Misevičiene, S. (2004). "Environmental evaluation of slurry applied on fields. / Trešimo skystuoju mešlu gamtosauginis vertinimas." Water Management Engineering 26(46): 12-18.	Jnl	Abst	20	Alteration of slurry application timing	Lithuania	4	Not clear	spring application v autumn application	NKP leaching	Not clear	Not clear	Not clear	Not clear	Not clear	Not clear	N,K,P leaching	Spring v autumn	Spring	Autumn	Yes	yes	yes		Spring application reduced N by 11.5% ,P		
17	Miseviciene, S.	2009	Misevičiene, S. (2009). Seasonal nitrogen leaching from fields applied by slurry. Annual 15th International Scientific Conference Proceedings "Research for Rural Development 2009", Latvia University of Agriculture	Conf proc	Abst		Alteration of slurry application timing	Lithuania	2	Not clear	autumn v winter v spring	Nitrate leaching	Not clear	Not clear	Not clear	Not clear	Not clear	Not clear	N leaching	Autumn v winter v spring	Spring	Autumn	Yes	yes			38.8% more N leached from autumn application		

ID	1sr author	year	reference	ref type	text read	linked study	intervention	country study	years of study	study type	control?	comparator	randomized	spatial replicate	temporal replicate	study scale	Location & method	soil type	measurements conducted	timings studied	best timing	worst timing	redcution?	N reduced	P reduced	fio reduced	comments on pollutant reduced	confounding	reasons for heterogeneity
18	Sagoo, E.	2006	Sagoo, E., J. R. Williams, et al. (2006). Nitrogen and phosphorus losses following cattle slurry applications to a drained clay soil at Brimstone Farm. DIAS Report, Plant Production. S. O. Petersen. Tjele; Denmark, Danmarks J	Conf proc	Full text		Alteration of slurry application timing, arable or grassland	UK	< 1 yr	Manipulative	autumm v winter v spring	Ammonium leaching, Nitrate leaching,	Not clear	Yes	Not clear	Farm	Plot, Automatic water samplers	Clay	N leaching, phosphate leaching, ammonium	Autumn v winter v spring	Spring for nitrate on arable land, no effect of timing on	Ammonium losses greatest during winter and spring	Variable	yes variable				Arable or grassland	Weather conditions
19	Schechtner, G.	1986	Schechtner, G. (1986). Economical use of slurry on grasslands without causing damages on soil, water and plants and with small odour emissions	Conf proc	Abst		Alteration of slurry application	Not clear	Not clear	Not clear	Not clear	Water pollution	Not clear	Not clear	Not clear	Not clear	Not clear	Not clear	Not clear	Not clear	Not clear	Not clear	Not clear	not clear					
20	Schröder, J. J.	1993	Schröder, J. J., H. L. d. Holte, et al. (1993). "Effects of nitrification inhibitors and time and rate of slurry and fertilizer N application on silage maize yield and losses to the environment." Fertilizer Research 34(3)	Jnl	Full text		Alteration of slurry application rate and timing, fertilizer type	The Netherlands	8	Manipulative	no manure or fertiliser	Nitrate losses	Not clear	Yes	Yes	Multi-Site	Plot, Ceramic cup	Sandy soil	N leaching, soil mineral N, residual soil mineral	Autumn v spring v late summer	Spring		Yes	yes			Spring slurry application without nitrification inhibitor	Rate	Trials were located at different sites except
21	Smith, K. A.	2002	Smith, K. A., C. P. Beckwith, et al. (2002). "Nitrate leaching following autumn and winter application of animal manures to grassland." Soil Use and Management 18(4): 428-434.	Jnl	Full text	3,7	Alteration of slurry application timing, fertilizer type, nitrificn	UK	4	Manipulative	no manure	Ammonium leaching, Nitrate leaching	Yes	Yes	Yes	Multi-Site	Plot, Ceramic cup	Coarse loam, coarse sandy soil, variable	N leaching, ammonium leaching	June then monthly applications Sept - Jan	Dec - Jan	September - November	Yes	yes			N/ammonium leaching reduced in December,		
22	Smith, K. A.	2001	Smith, K. A., D. R. Jackson, et al. (2001). "Nutrient losses by surface run-off following the application of organic manures to arable land. 1. Nitrogen." Environmental Pollution 112(1): 41-51.	Jnl	Full text		Alteration of slurry application rate and timing	UK	4	Manipulative	mineral fertilizer, Yes - no manure	Ammonium leaching, Nitrate	Yes	Yes	Not clear	Site	Plot, Water soluble tracers	Silty clay loam	N leaching, ammonium leaching	Spring v autumn v half spring half	Not clear	Not clear	No conclusions made		reported elsewhere		Total losses of NH4 and NO3 during the	Rate	Weather conditions (especially rainfall)

ID	1sr author	year	reference	ref type	text read	linked study	intervention	country study	years of study	study type	control?	comparator	randomized	spatial replicate	temporal replicate	study scale	Location & method	soil type	measurement s conducted	timings studied	best timing	worst timing	redcution?	N reduced	P reduced	fio reduced	comments on pollutant	confounding	reasons for heterogeneity
23	Smith, K. A.	2001	Smith, K. A., D. R. Jackson, et al. (2001b). "Nutrient losses by surface run-off following the application of organic manures to arable land. 2. Phosphorus." Environmental Pollution 112(1): 53-60.	Jnl	Full text	28	Alteration of slurry application timing	UK	4	Manipulative	mineral fertilizer, Yes - no manure	Phosphate leaching	Yes	Yes	Not clear	Site	Plot, Water soluble tracers	Silty clay loam	P leaching	Spring v autumn v half spring half autumn	2 dressings - November and March	Single application in November	Yes		yes		P leaching reduced by 2 dressings -		
24	Sorensen, P.	2012	Sorensen, P. and G. H. Rubaek "Leaching of nitrate and phosphorus after autumn and spring application of separated solid animal manures to winter wheat." Soil Use and Management 28(1): 1-11.	Jnl	Full text		Manure type, alteration of slurry application timing	Denmark	2	Manipulative	mineral fertilizer	Nitrate leaching, Phosphate leaching	Not clear	Yes	Yes	Site	Lysimeter	Sandy loam	N leaching, P leaching	Spring v autumn	With spring application the rise in nitrate	High risk of increased nitrate leaching when	Variable	not clear	not clear		combination of solid manure and slurry	manure type	
25	Thomsen, I. K.	2005	Thomsen, I. K. (2005). "Crop N utilization and leaching losses as affected by time and method of application of farmyard manure." European Journal of Agronomy 22(1): 1-9.	Jnl	Full text		Alteration of slurry application timing, Application	Denmark	3	Manipulative	Sept, Dec, Mar application	Crop uptake of N, Nitrate leaching	Not clear	Yes	Not clear	Site	Lysimeter	Sandy loam	N leaching, crop yield, crop uptake	Sept, Dec, Mar	Winter or spring	Autumn	Yes	yes			N leaching reduced in winter and spring		
26	Trindade, H.	2009	Trindade, H., J. Coutinho, et al. (2009). Grass and Forage Science 64(1): 2-11.	Jnl	Full text		Alteration of slurry application	Portugal	3	Manipulative	no manure or fertilizer	Crop uptake of N, Crop yield,	Not clear	Yes	Not clear	Site	Plot	Sandy loam	Crop uptake of N, Crop yield	May, July, October	3 annual applications		Yes	yes			Yes leaching potential	Rate	
27	Trindade, H.	2006	Trindade, H., J. L. Pereira, et al. (2006). Effect of time and rate of cattle-slurry application on nitrate concentration of drainage water in a double-cropping forage system. DIAS Report, Plant Production. S. O. Petersen. Tjele; Denmark	Conf proc	Full text		Alteration of slurry application rate and timing	Portugal	3	Manipulative	no manure	Nitrate leaching	Yes	Yes	Yes	Site	Plot, Ceramic cup	Sandy loam	N concentration in drainage water	Application at sowing, 2 applications at sowing (1	Not clear	Not clear	Not clear	not clear				Rate	

ID	1sr author	year	reference	ref type	text read	linked study	intervention	country study	years of study	study type	control?	comparator	randomized	spatial replicate	temporal replicate	study scale	Location & method	soil type	measurements conducted	timings studied	best timing	worst timing	redcution?	N reduced	P reduced	fio reduced	comments on pollutant	confounding	reasons for heterogeneity
28	Vetter, H.	1978	Vetter, H. and G. Steffens (1978). "Influence of varying rates and application times of slurry on nutrient leaching into deep soil layers and groundwater. Landwirtschaftliche Forschung, Sonderheft 34(2): 238-246.	Jnl	Abst		Alteration of slurry application rate and timing. Soil type	Not clear	Not clear	Not clear	Not clear	Nitrate leaching	Not clear	Not clear	Not clear	Not clear	Not clear	Sandy soil and loamy soil	N leaching	October or August v February or March	February or March	October or August	Yes	yes					
29	Vetter, H.	1981	Vetter, H. and G. Steffens (1981). "Displacement and leaching of nutrients into the shallow groundwater after slurry application. Zeitschrift fur Kulturtechnik und Flurbereinigung 22(3): 159-172.	Jnl	Abst		Alteration of slurry application rate and timing, fertilizer type	Not clear	Not clear	Not clear	Not clear	Nitrate leaching , phosphate leaching	Not clear	Not clear	Not clear	Not clear	Not clear	Sandy soil and heavier soils	N leaching, P leaching	Spring v autumn	Spring	Autumn	Yes	yes	not clear		N leaching reduced 23% in spring		
30	Williams, J. R.	2007	Williams, J. R., L. Sagoo, et al. (2007). The impact of slurry management practices to reduce nitrate leaching on phosphorus losses from a drained clay soil. The 5th International Phosphorus Workshop (IPW5) in Silkeborg	Conf proc	Abst	24	Alteration of slurry application timing, arable or grassland	UK	2	Manipulative	autumn v winter v spring	Nitrate leaching , phosphate leaching	Not clear	Not clear	Not clear	Farm	Water drainage/Drain	Clay	N leaching, P leaching	Autumn v winter v spring	Not clear	Winter for P .	Not clear	yes	not clear		N leaching most in autumn on arable. P		Weather conditions
31	Harold, M. van Es	2006	Harold, M. van Es (2006) "Effect of Manure Application Timing, Crop, and Soil Type on Nitrate Leaching." J. Environ. Qual. 35: 670–679	Jnl	Full text		Alteration of slurry application timing, Crop type, Soil type	USA (New York)	3	Manipulative	mineral fertilizer	Nitrate leaching	Not clear	Yes	Yes	Site	Plot, Water drainage/Drain	Clay loam & Stafford loamy fine	N leaching, crop yield	Spring v autumn v spring and autumn	Single spring application	Autumn for N arable. Winter for P	Yes	yes			N leaching significantly reduce		

32	Turtola, E.	1998	Turtola, E. (1998) "Nitrogen and phosphorus losses in surface run off and drainage water after application of slurry and mineral fertilizer to perennial grass ley." Agricultural and Food Science in Finland. 7: 569-581	Journal	Full text		Alteration of slurry application rate and timing	Finland	4	Manipulative	no manure or fertilizer	Nitrate leaching , phosphate leaching	Yes	Yes	Yes	Site	Plot, Water drainage/Drain	Fine sand	N leaching, P leaching	Autumn v winter v spring	Not clear as large P losses were also observered in	Autumn and winter (for both N and P)	yes	yes	yes			Rate	Soil compaction, weather conditions
33	Downing, T.W	2008	Downing, T.W. (2008) "Case study: Impact of manure application timing in dairy pastures on the migration of nitrates to ground water." The Professional Animal Scientist. 24: 100-102	Journal	Full text		Alteration of slurry application rate and timing	USA (Oregon)	2	Correlative	No	Nitrate leaching	Not clear	Yes	Yes	Multi-Farm	Plot, Lysimeter	Clay loam	N leaching	Not clear	Not clear	Not clear	Not clear	not clear				Rate	Different crop types and grazing systems
34	Uusi-Kämppä, J.	2001	Uusi-Kämppä, J. and H. Heinonen-Tanski (2001). Runoff of nutrients and faecal micro-organisms from grassland after slurry application. DIAS Report, Animal Husbandry. H. B. Rom and C. G. Sorensen. Tjele; Denmark, Danish Institute of Agricultural Sciences.	Conf proc	Abst	14	Alteration of slurry application timing, Appl tech, fertilizer type	Finland	2	Manipulative	mineral fertilizer	Feacal organisms in runoff, N, P leaching	Not clear	Not clear	Not clear	Site	Not clear	Clay	N leaching, P leaching, feacal organisms in runoff	Summer v autumn	Not clear	High autumn rainfall led to immediate increases in	Not clear	not clear	not clear		abstract only and confounding factors		Weather conditions