The Value of On-farm Interventions for Improving Water Quality. What is the Evidence?

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

This report is funded by the Department of Food and Rural Affairs (Defra) and summarises work funded by Defra and by the Natural Environment Research Council (NERC) including work carried out under Defra work order WT0965

Summary

This study used systematic mapping and systematic review methodology to collate and assess the state of water quality research, for five on-farm interventions relevant to the UK: Slurry storage, Cover/catch crops, Woodland creation, Break-up of compacted layers/controlled trafficking, Buffer strips. In addition, a Rapid Evidence Assessment (REA) was used to collate and assess the state of water quality research relating to changes to timing of slurry application. Changes in one or more of 5 measurements were investigated: Nitrogen (N), Phosphorous (P), Bacterial pathogen counts, Pesticides, and Sediments.

Buffer strips
Buffer strips composed of grass and/or trees can improve water quality by physically trapping sediments and associated pollutants, and by immobilizing soluble nutrients through plant uptake or microbial degradation. The evidence indicated that buffer strips are most effective for reducing sediment, followed by pesticides, N, P, and bacterial pathogens (in decreasing order). Buffer design and management varies greatly, and this variation is likely to impact on their efficacy for reducing pollutant transport into water bodies.

Cover/catch crops
Fast-growing cover or catch crops, planted over the winter months can potentially improve water quality by protecting soil against erosion thereby minimizing the risk of runoff, and by reducing the risk that nutrients are leached from the root zone. The Evidence indicated that cover crops are most effective at reducing leaching of N and of sediments into water bodies.

Slurry application
Storing slurry and altering the timing of application to crops can impact on water quality by timing applications for maximum uptake of nutrients by crops. The evidence was variable, but indicated that levels of bacterial pathogens reduce during slurry storage. The REA indicated that autumn slurry applications often cause worse leaching (particularly of N) than other times of year, and spring application can reduce N leaching compared to autumn.

Woodland creation
Woodland creation can potentially improve water quality by improving soil water infiltration thereby reducing water runoff and the risk of pollutants entering water sources, and by up taking of nutrients which would otherwise be lost to water sources. Much of the evidence found in this review related to buffer strips composed of trees, and is therefore considered in the buffer strip section. Other woodland creation studies found were limited as most research falls outside the scope of the question investigated here, but studies investigating the wider benefits of trees for water are extensive and are reported elsewhere.

Controlled trafficking and subsoiling
The confinement of farm machinery to certain areas of a field (controlled trafficking) or the breaking up of compacted soil layers (subsoiling) by a mechanical soil treatment has the potential to reduce runoff by reducing soil compaction to improve soil infiltration and root penetration. Studies that directly investigated this intervention were limited. A synthesis of the evidence for the effectiveness of controlled trafficking/subsoiling on related factors (such as soil infiltration) is likely to be more effective.

Lessons learned from the reviews
A number of issues were identified during the review and have been summarised as recommendations to improve the value research for future evidence syntheses.

Commissioning primary research:
Before/after and control/intervention (BACI) designs enable impact of interventions to be assessed most effectively, and should be employed wherever feasible.

Commissioning evidence reviews and syntheses:
There is a need to ensure that questions for evidence syntheses are appropriate to the evidence required and the review method to be used. For example, broad questions enable different interventions to be compared, but more focussed questions allow evaluation of the factors that influence the efficacy of specific interventions.

Reporting of primary research:
Reports of primary research should contain details of the methodology and statistics applied. Once reports are submitted to Defra they should be carefully archived and made publically available.

Reporting and interpretation of evidence syntheses:
Evidence syntheses often collate extensive information relating to relevant research. This research information (e.g. systematic map databases) can provide valuable resources for users, and should be archived.

The outputs of evidence syntheses vary, and should be interpreted within the context of the research. The evidence presented here was subject to many limitations, and the evaluation of study designs was very basic. Formal meta-analyses is needed in order to enable a more accurate assessment of intervention effectiveness.

Background

Over the last fifty years, European agriculture has become more intensive due to increased applications of fertilizers and agrochemicals to agricultural land. Currently 50% of the nitrates in European rivers are estimated to be from agricultural sources.

In the UK, agriculture activities are estimated to contribute 70% of nitrates, 28% of phosphates and 76% of sediments measured in rivers. River waters of catchments dominated by agricultural land use can have elevated levels of pesticides and bacterial pathogens. European member states have a policy commitment to tackle this water pollution through the Water Framework Directive.

Aim of the study

An analysis of the effectiveness of water pollution intervention measures should enable decision makers and delivery agencies to better facilitate catchment planning. This study used systematic mapping and systematic review methodology to collate and assess the state of water quality research, relevant to the UK, for five on-farm interventions.

Interventions assessed

Slurry storage
Cover/catch crops
Woodland creation
Break-up of compacted layers/controlled trafficking
Buffer strips.
Changes to timing of slurry application (considered in a separate synthesis)

Outcomes measured

Changes in one of the 5 following measurements were used to assess the effect of interventions on water quality:

Nitrogen (N)
Phosphorous (P)
Bacterial pathogen counts
Pesticides
Sediments

Outputs

This evidence summary has been compiled using databases of relevant research created as part of two defra funded projects [1,2]

References

[1] Randall N.P., Donnison L.M. and Lewis P.J. (In prep) *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? Defra project report WT0965.* Defra.

[2] Waterson A. and Randall N.P. (In prep) *What Impact does the Alteration of Timing to Slurry Applications have on Leaching of Nitrate, Phosphate and Bacterial Pathogens? A Rapid Evidence Assessment.* Defra

How was the evidence selected and assessed?

Electronic databases and organisation websites were searched for relevant studies. Figure 1 shows the searching and inclusion process for 5 of the interventions. 718 studies were placed in a database, which is searchable by topic. A separate Rapid Evidence Assessment was carried out for research relating to the timing of slurry application.

Studies found at full text were given a value for study design, as shown in Table 1. The combined study design values provide an indication of the overall scientific rigour of the evidence available for each intervention. If studies had confounding factors (where multiple interventions were assessed, and it was unclear which influenced the outcome), they were given a value of zero.

Full text studies without confounding factors were given a second value (out of 3, for the effectiveness of the intervention(s) for reducing the pollutant(s) tested.

The combined values provide a basic indication of the overall effectiveness of each intervention for improving water quality.

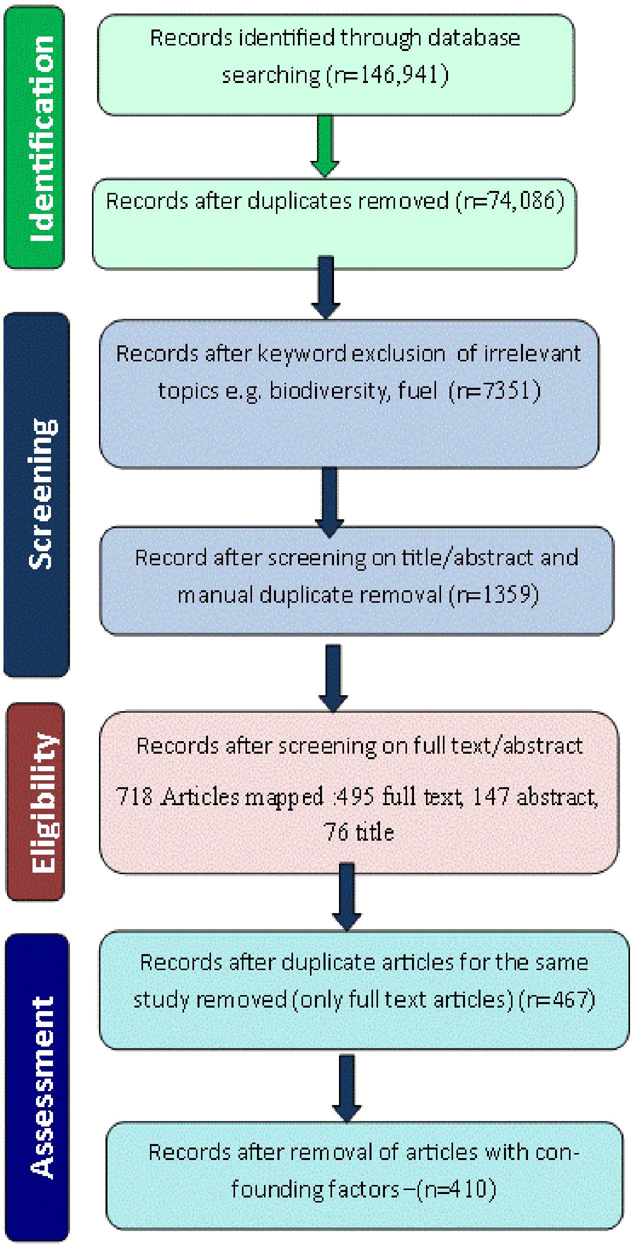

Figure 1. Literature inclusion process used for systematic review and map.

	Score **3**	**2**	**1**	**0**
Randomized	-	-	yes	No/not clear
Study type	Manipulative	Correlative	Monitoring	Sampling
Replicated	-	Spatial and temporal	Spatial or temporal	No
Control	Before/after control intervention	Control	Comparator	None
Study length	-	-	> 1 year	< 1 year

Table 1. Values for five different factors, applied to studies, in order to provide an indication of comparative scientific rigour

Overall trends in evidence for all mitigations

Figure 2 summarises some of the general findings from the literature.

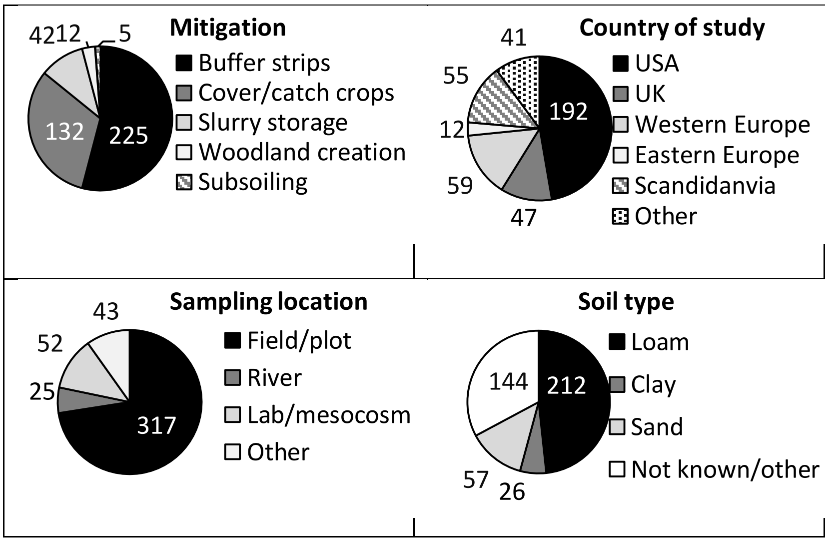

Figure 2. Summary charts showing mitigation type, country of study, sampling location, and soil type (total numbers and proportions) for studies found at full text and with no confounding factors. Some studies appear in multiple categories.

- Buffer strips (including woodland buffers) were the most commonly studied intervention.
- The direct effect of subsoiling on water quality was rarely studied
- The USA was the most common country of study.
- Water quality was mostly sampled in fields or plots rather than within river systems.
- Loam was the most common soil type studied, although sometimes the soil type was not reported.
- N was the most commonly measured water quality indicator.
- Approximately a quarter of the studies made measurements in all 4 seasons

Study design - general trends across all mitigations.

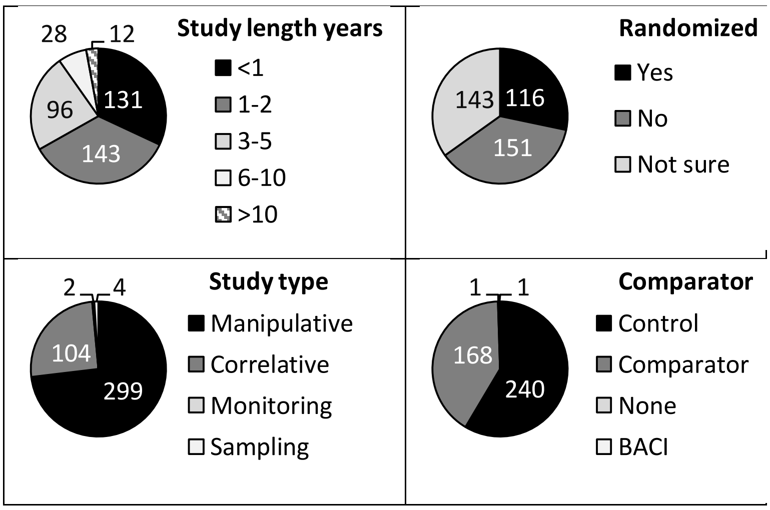

Figure 3. Summary charts showing study length, randomization, type, and comparator (total numbers and proportions), for studies found at full text and with no confounding factors. Some studies appear in multiple categories.

- Study designs varied within and between mitigations. Some of the general trends are shown in Figure 3.
- Approximately two thirds of the studies were conducted for 2 years or less.
- Randomization was used in a third of the studies, and most studies were replicated either temporally or spatially.
- Nearly three quarters of the studies were manipulative. The remaining were predominantly correlative.
- Over half of the studies used a control. This rarely included measurements pre and post intervention.
- Comparators were often changes in water quality over time or physical space.

How scientifically rigorous was the evidence for each mitigation?

- Slurry storage had a lower scientific rigour value than cover crops or buffer strips (Table 2), although the focus and design of slurry store studies was diverse, ranging from sampling of leakage from stores, to pathogen degradation over time. They also often had confounding factors as they were part of catchment studies. This highlights the difficulty in measuring water quality from within river systems.

- Cover crop studies had the highest proportion of randomized, controlled, manipulative experiments.

Mitigation	Value
Buffer Strips	6
Cover/catch crops	7
Slurry Storage	4

Table 2. Average rounded scientific rigour values (out of 10) for three interventions, based on study type, randomisation, length of study , controls, and replication.

- Woodland creation and subsoiling studies are excluded from Table 2 due to the low numbers of studies found for these specific outcomes, but approximately 50% of buffer strip studies included woodland, and were considered under this intervention instead.

Evidence of intervention efficacy for improving water quality.

Effectiveness values were calculated based on author reporting. The comparative effectiveness values for buffer strips, cover crops, and slurry storage are shown in Table 3.

- Overall, study authors suggested that cover/catch crops and buffer strips can be effective for improving water quality; however the evidence is generally based on short term studies conducted at a field or plot scale.

- Slurry storage had comparatively low effectiveness values. However the evidence was often based on studies investigating slurry stores that were outside current UK legislation, both geographically and temporally. Alteration of slurry application timing was considered in a separate synthesis and scored independently.

- Variations in intervention effectiveness was often due to the water quality measure and method applied, and this varied within and between interventions and pollutants.

Average effectiveness values	N	P	Sediment	Bacterial	Pesticide
Buffer Strips	2.2	2.0	2.7	1.8	2.3
Cover/catch crops	2.3	1.2	2.3		
Slurry Storage*	1.0	1.0		2.2	

Table 3. Average effectiveness values out of 3, where 3 is pollutant completely reduced, 2 partially, 1 unclear or 0 not reduced.

* Slurry storage figures often related to leakage from stores (rather than reduction in pollutants), and should be interpreted with caution as many studies tested slurry stores that do not meet current UK regulations Slurry storage values do not include studies investigating the impacts of alterations to slurry application timings.

References of interest

Burke A: *Synthesis of Diffuse Pollution Research in England and Wales funded by Department for Environment, Food and Rural Affairs and Environment Agency.* UK: Demonstrating Catchment Management; 2011.

Newell Price JP, Harris D, Taylor M, Williams JR, Anthony SG, Duethmann D, Gooday RD, Lord EI, Chambers BJ, Chadwick DR, Misselbrook TH: *An Inventory of Mitigation Methods and Guide to their effects on Diffuse Water Pollution, Greenhouse Gas Emissions and Ammonia Emissions from Agriculture.* UK: Department for Environment, Food and Rural Affairs; 2011.

Buffer strips (including wooded buffers)

Buffer strips composed of grass and/or trees can improve water quality by:

- Physically trapping sediments and associated pollutants.
- Immobilizing soluble nutrients through plant uptake or microbial degradation

The evidence indicated that:

- Buffer strips are most effective for reducing sediment, followed by pesticides, N, P, and bacterial pathogens (in decreasing order), but that buffer design and management varies greatly and is these factors are likely to impact on efficacy.

What type of evidence was found?

- Almost two thirds of the studies were conducted in the USA.
- Field plots were the most common sampling location, although, 23 studies sampled river water.
- Loam was the most commonly studied soil type.
- All vegetation types were well represented.
- Figure 4 summarises the type of studies found for buffer strips.

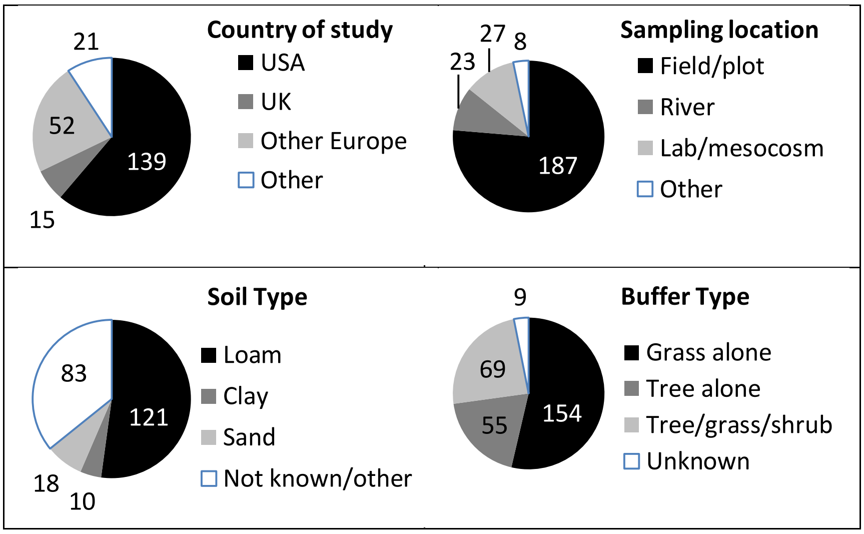

Figure 4. Summary charts showing country of study, sampling location, soil type and buffer type (total numbers and proportions), for buffer strip studies found at full text and with no confounding factors. Some studies appear in multiple categories.

How variable is the evidence?

- Vegetation was a common experimental factor (type, age, height, density, harvesting).
- Other common experimental factors were fertilizer (type, amount and inflow), buffer width, soil type and landscape (slope and drainage) (Figure 5).

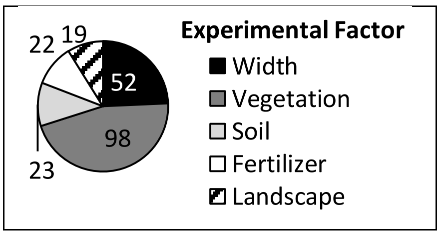

Figure 5. Common experimental factors investigated in buffer strip studies (proportion of studies). Some studies appear in multiple categories.

How scientifically rigorous is the evidence?

Over half of the studies were manipulative, and at least a third were controlled and fully replicated (Figure 6). Nearly half of the studies were conducted for longer than a year, but few were randomized, which resulted in an overall value of 5.9 out of 10 for study design (standard deviation 2.4).

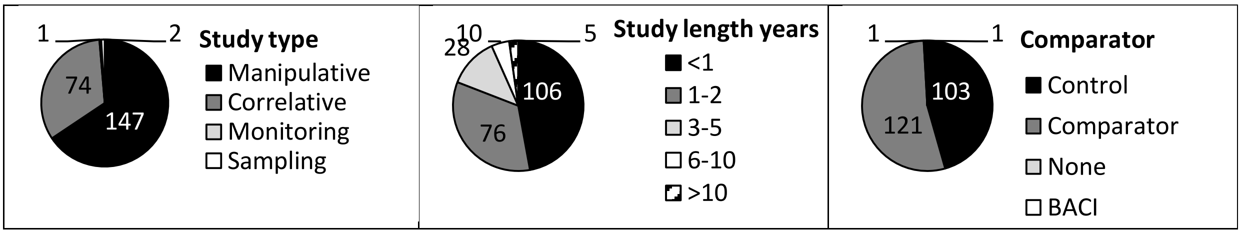

Figure 6. Summary charts showing study type, length and comparator (total and proportion) for buffer studies.

What are the limitations of the evidence?

- Buffer strip effectiveness was often assessed at field scale, which may not capture the effects of preferential flow paths or buffer strip placement on performance.
- Most studies were carried out on loam or unspecified soil types, and so may not capture the effect of soil particle size on buffer strip performance.
- Studies often took place over short periods of time, and so may not capture changes in buffer strip effectiveness over time e.g. saturation with P.
- This review has not investigated how variations in experimental factors, such as vegetation type, have impacted on the effectiveness of buffer strips.

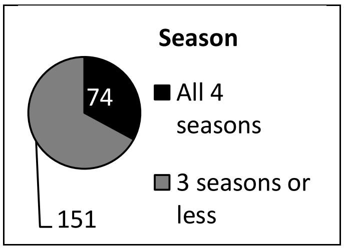

Figure 7. Proportion of buffer strip studies that took place over all 4 seasons, or less.

- Only a third of the studies had data for all four seasons (Figure 7), yet seasonal differences, such as plant growth and nutrient uptake, may have an impact on effectiveness.
- This review excluded studies that assessed other benefits of buffer strips, such as reductions in aerial pollutants and pesticide drift.

How effective are buffer strips at improving water quality based on this evidence?

- Average effectiveness values suggested that buffer strips were most effective for reducing sediment, followed by pesticides, N, P, and bacterial pathogens (in decreasing order) (Table 4), however these values should be interpreted within the limitations of the evidence.
- Pre-existing meta-analyses[3,4] also found that buffer strips could be effective in improving water quality.

	N	P	Sediment	Pathogen	Pesticide
Mean	2.2	2	2.7	1.8	2.3
N	139	94	98	19	38
s.d.	1.1	1.2	0.8	1.3	1.1

Table.4. Effectiveness values calculated for buffer strips for each pollutant, based on author reporting for each study. For each pollutant the mean across all included studies is given, together with the total number of studies (N) included, and the standard deviation (s.d.)

Nitrogen

- N was the most frequently measured water quality measurement.
- Authors indicated that buffer strips often reduced N, but results varied for different forms of N (Figure 8), resulting in an overall effectiveness value of 2.2.

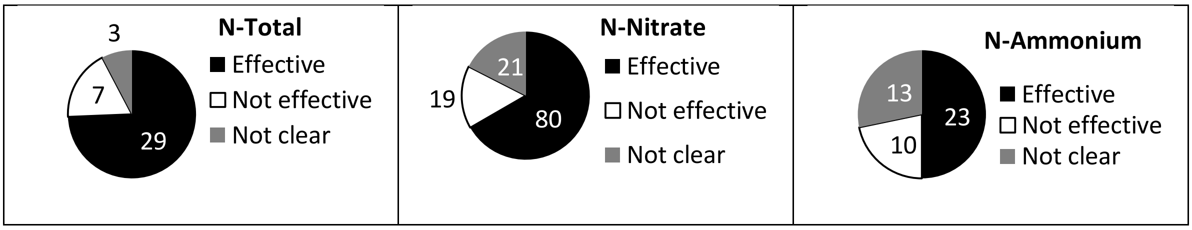

Figure 8. Effectiveness of buffer strips for reducing three different forms of N (total and proportion of studies)

Sediment

- Sediments were frequently measured.
- Authors indicated that buffer strips are generally effective for reducing sediments (Figure 9), which resulted in an overall value of 2.7 for effectiveness.

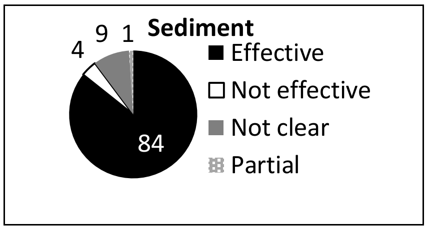

Figure 9. Effectiveness of buffer strips for reducing sediment (total and proportion of studies).

Phosphate

- P was quite frequently measured.
- Authors indicated that buffer strips often reduced P, but sometimes results varied depending on the form of P (Figure 10). This resulted in an overall value of 2 for effectiveness. Some studies suggested that buffer strips ability to reduce P declined over time due to P saturation.

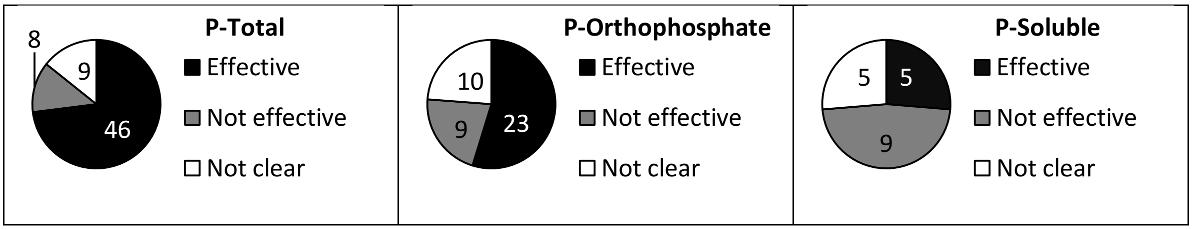

Figure 10. Effectiveness of buffer strip for reducing three different forms of P (total and proportion of studies)

Pesticides

- 35 different pesticides were studied in 38 studies. Atrazine and Metolachlor were the most commonly studied pesticides.
- Authors indicated that buffer strips often reduced pesticide levels, but sometimes results varied depending on the type of pesticide used. An overall value of 2.4 was calculated for effectiveness.

Bacterial pathogen counts

- Bacterial pathogen counts were measured in 19 studies.
- An overall effectiveness value of 1.8 indicated that buffer strips were comparatively less effective at reducing bacterial pathogen counts than the other pollutants measured.

Policy Implications

- Overall, the evidence supports existing guidance for the use of buffer strips alongside water courses to improve water quality, although buffer strip implementation, design and management is very variable, and the research studies reflect this.

- This could be an important consideration in further refining and strengthening current tools e.g. increasing resilience of buffer strip options within Farmscoper'

Research gaps and recommendations for further primary research

- Studies were often short-term, and predominately measured water quality within field plots. The use of multiple sampling locations and studies over longer periods of time would enhance the evidence base.
- Further work could examine the collated evidence in more detail to understand under which conditions buffer strips perform best. It may be of value to separate out results based on flow path (subsurface, surface) or vegetation type (grass or tree)

- Longer term studies should investigate differences between vegetation types, particularly between trees and low growing vegetation.
- Further analysis of the 38 pesticide studies may be beneficial before conducting further primary research.
- Few studies measured bacterial pathogen counts. Further research may be beneficial.

References of interest

Angier JT, McCarty GW: Variations in base-flow nitrate flux in a first-order stream and riparian zone. *Journal of the American Water Resources Association* 2008, 44:367-380.

[3]Mayer PM, Reynolds SK, McCutchen MD, Canfield TJ: Meta-analysis of nitrogen removal in riparian buffers. *Journal of Environmental Quality* 2007, 36:1172-1180.

Stutter MI, Chardon WJ, Kronvang B: Riparian Buffer Strips as a Multifunctional Management Tool in Agricultural Landscapes: Introduction. *Journal of Environmental Quality* 2012, 41:297-303.

[4]Zhang X, Liu X, Zhang M, Dahlgren RA, Eitzel M: A review of vegetated buffers and a meta-analysis of their intervention efficacy in reducing nonpoint source pollution. *Journal of Environmental Quality* 2010, 39:76-84.

Leeds-Harrison PB, Quinton JN, M.J.Walker, K.S.Harrison, D.J.Gowing, S.F.Tyrrel, J.Morris, J.Mills, T.Harrod: *Report NT1101 Buffer zones.* UK: Department for Environment, Food and Rural Affairs; 1996.

Cover and catch crops

Fast-growing cover or catch crops, planted over the winter months can potentially improve water quality by:

- Protecting the soil against erosion thereby minimizing the risk of runoff
- Reducing the risk that nutrients are leached from the root zone

The Evidence indicated that:

- Cover crops are most effective at reducing leaching of N and of sediments into water courses

What type of evidence was found?

- Figure 11 summarises the type of evidence found for cover crops.
- Over two thirds of studies were conducted in the UK or other European countries.
- Field plots were the most common sampling location only one study sampled within a river system.
- Loam was the most commonly studied soil type.
- Cereal and grass were the most commonly studied cover/catch crops.

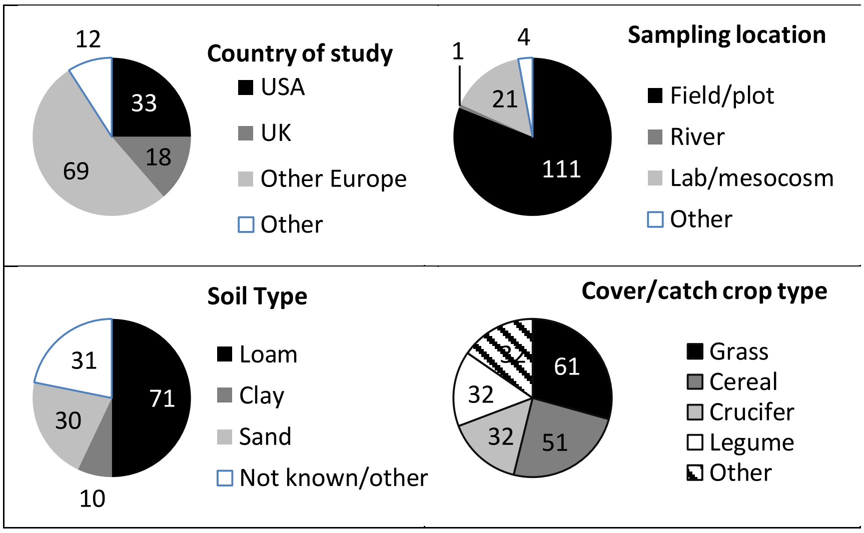

Figure 11. Summary charts showing country of study, sampling location, soil type and cover/catch crop type (total numbers and proportions), for cover/catch crop studies found at full text and with no confounding factors. Some studies appear in multiple categories.

How variable is the evidence?

- Crop type was a common experimental factor (cash crop, rotation series or cover/catch crop type) (Figure 12).
- Fertilizer (type, amount, date of application), soil type, tillage (date, type) and kill date of cover/catch crop were also common experimental factors.

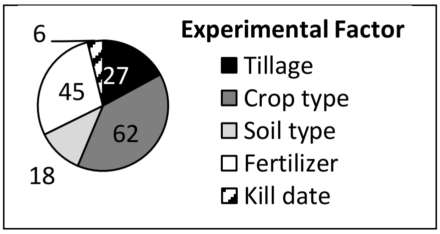

Figure 12. Common experimental factors investigated in cover/catch crop studies (proportion of studies). Some studies appear in multiple categories.

How scientifically rigorous is the evidence?

Most studies were manipulative, and often controlled and fully replicated. Over half of the studies were conducted for more than 2 years, and some were randomized (Figure 13). This resulted in an overall scientific rigour value of 6.8 out of 10, with a standard deviation of 3.1.

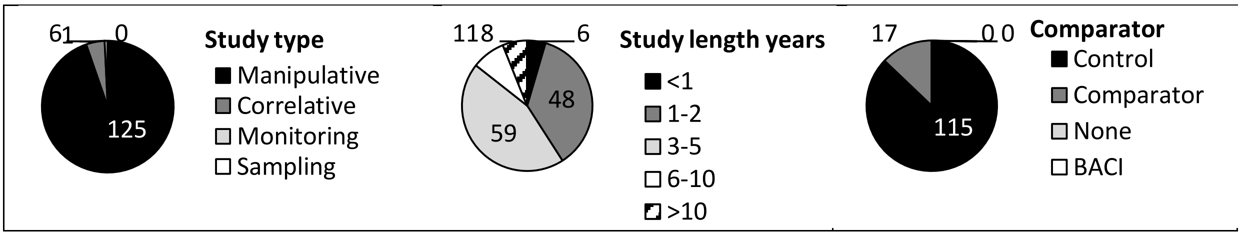

Figure 13. Summary charts showing study type, length and comparator (total and proportion) for cover crop studies.

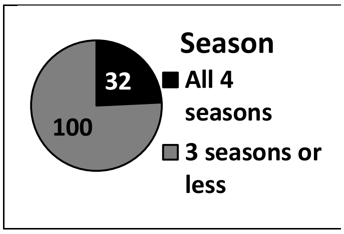

Figure 14. Proportion of cover/catch crop studies that took place over all 4 seasons, or less.

What are the limitations of the evidence?

- Studies were mainly at a field scale, which does not necessarily translate to larger scales.
- Cover and catch crop studies were often conducted on loam or unknown soil types, and so may not capture relationships between soil types and nutrient leaching
- Only a quarter of the studies assessed effectiveness across all 4 seasons (Figure 14).
- Although some studies were of long duration (up to 30 years), the effect of stopping cover/catch cropping was rarely studied. Two studies that did, suggested that nutrients caught by cover/ catch crops can be leached in subsequent years if no cover/catch crop is subsequently planted.
- Climatic data was often difficult to extract from studies, however some studies reported that year to year effectiveness varied depending upon the date when autumn rains started.

How effective are cover catch crops at improving water quality based on this evidence?

Average effectiveness values suggested that cover/catch crops were most effective for reducing N and sediments, but not P (Table 5). However these values should be interpreted within the limitations of the evidence.

	N	P	Sediment
Mean	2.3	1.2	2.3
N	114	14	19
s.d.	1	0.9	1.1

Table.5. Effectiveness values calculated for cover/ catch crops for each pollutant, based on study author reporting. For each pollutant the mean across all included studies is given, together with the total number of studies (*N*), and the standard deviation (s.d.)

Nitrogen

- N was the most frequently measured pollutant, mostly measured as nitrate.
- Authors indicated that cover/catch crop often reduced N (Figure 15), resulting in an overall value of 2.3 for effectiveness.

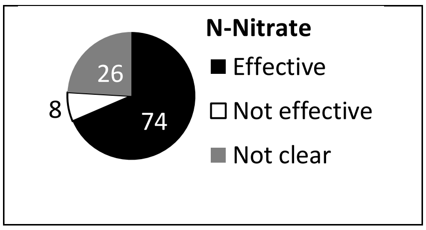

Figure 15. Effectiveness cover/catch crops for reducing sediment (total and proportion of studies).

- A meta-analysis on a small subset of the data (data from 10 studies), suggested that cover/catch crops were effective at reducing nitrate leaching as compared to a fallow control. There was little variation within studies, but lots between studies. The meta-analysis showed no difference in effectiveness between cereals and brassica cover crops.

Sediment

- Sediments were measured in a few studies.
- Authors indicated that cover/catch strips can be effective for reducing sediments (Figure 16), which resulted in an overall value of 2.2 for effectiveness.

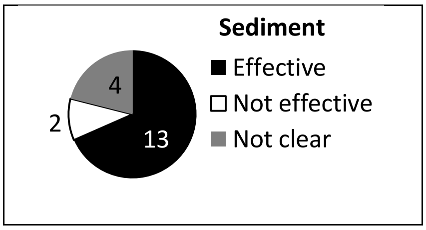

Figure 16. Effectiveness of cover/catch crops for reducing sediment (total and proportion of studies).

Phosphate

- P was measured in a few studies, which were quite variable.
- Authors indicated that cover/catch crops were not that effective at reducing P.

Policy Implications

- The evidence generally supports the implementation of cover crops for reducing pollutants into water bodies.
- Results were often compared to a fallow or cash crop control, and rarely investigated whether catch crops were more effective than a cropped cover e.g. winter wheat.

Research gaps and recommendations for further primary research

- Further work could examine the collated evidence in more detail, to understand under which conditions cover/catch crops perform best.
- Only 1 study sampled at a river location. Further research should try to address these limitations when possible.
- More in depth analysis should consider the effect of the full 4 seasons rather than just the winter period.

References of interest

Defra: OF0118T *Optimisation of nitrogen mineralisation from winter cover crops and utilisation by subsequent crops*. 2000.

Defra: NT1526. *The contribution of cover crops incorporated in different years to nitrogen mineralisation.*

Tonitto C, David M, Drinkwater L: Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. *Agriculture, ecosystems & environment* 2006, 112:58-72.

Slurry Application

Slurry storage and altering timing of slurry application to crops can impact on water quality by:

- Ensuring that slurry applications are timed to improve uptake of nutrients by crops

The evidence was variable, but indicated that:

- Storage can reduce the levels of bacterial pathogens in slurry
- Autumn slurry applications often cause worse leaching (particularly of N) than other times of year, and spring application can reduce leaching of N, compared to autumn.

What type of evidence was found?

- Figure 17 summarises the types of evidence found for slurry storage. Over half of the studies were from outside Europe and/or over 12 years old. Studies of earth lined slurry storage dominated the evidence.
- A Rapid Evidence Assessment (REA) found 34 studies that investigated the impact, on leaching, of altering the timing of slurry application. 10 were from the UK, and approximately 2/3 (21) were published in 2001 or later.

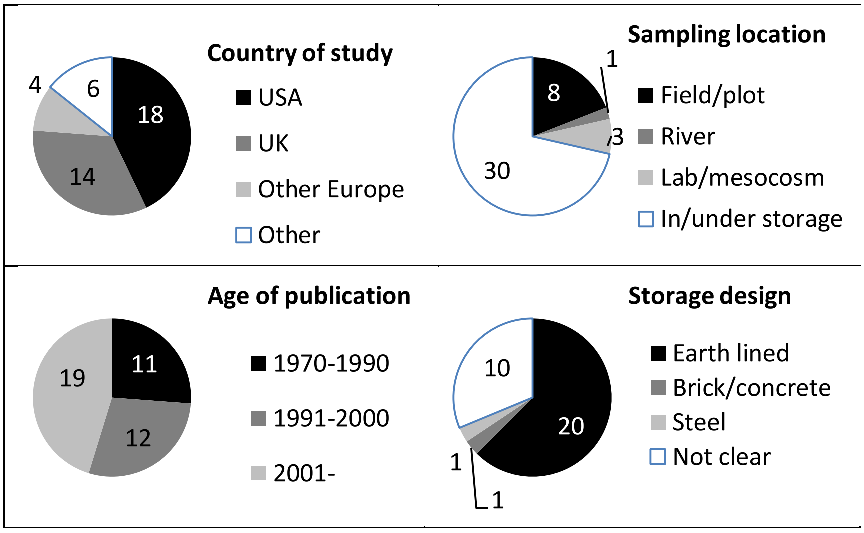

Figure 17. Summary charts showing country of study, sampling location, soil type and storage design (total numbers and proportions), for slurry storage studies found at full text and with no confounding factors. Some studies appear in multiple categories.

How variable is the evidence?

- Slurry storage studies were variable. If an experimental factor was used, it usually related to slurry storage design or age, slurry spreading (date or amount) or slurry properties (temperature or length of time stored) (Figure 18).
- Slurry application timing studies were also very variable in design and in the times compared.

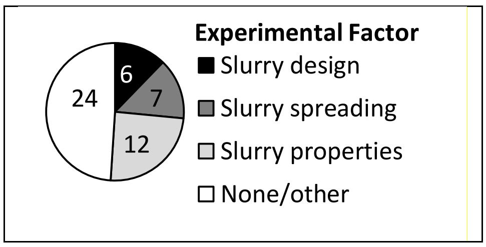

Figure 18. Common experimental factors investigated in slurry storage studies (proportion of studies). Some studies appear in multiple categories.

How scientifically rigorous is the evidence?

Less than half of the slurry storage studies were manipulative, controlled or fully replicated. Only 1/4 were conducted for more than 2 years. Studies were often not randomized (Figure 19). This resulted in an overall value of 4.2 out of 10 for study design (standard deviation 3.1). In contrast 21 of the 23 slurry application timing studies, found at full text in the REA, were manipulative, and most had replicates. Many studies had confounding factors and for the REA these were not given values for study design, but for the 8 that were, the mean value for study design was 8 out of 10.

What are the limitations of the evidence?

- Most of the evidence for slurry storage related to studies measuring leakage from slurry stores (particularly for N and P), and many of the slurry storage studies were either from outside of Europe (and so under different legislation, or were over 12 years old & used earth lined slurry stores that may not meet current UK legislation.
- Scientific rigour for slurry storage studies was variable, and study authors voiced a number of concerns including the following:
    - Results for leakage may have been due to experimental error e.g. slurry stores being completely emptied, resulting in clay soils cracking.
    - Spraying of slurry on adjacent fields may have contaminated water sources, rather than the slurry storage unit.
    - It was not possible to identify if the slurry had leaked as part of the initial sealing or later when the storage was operational.
- Most evidence for changing the timing of slurry application related to N, with very few studies investigating the impact of changing timing of slurry application on leaching of P. Many studies were found at abstract only, were poorly reported, or had confounding factors and could not be assessed for effectiveness of the intervention.

How effective is slurry storage/variations to slurry application timing at improving water quality based on this evidence?

- Average effectiveness values suggested that slurry storage can reduce levels of bacterial pathogen counts over time (Table 6).
- Seven of the 8 slurry application timing studies assessed for intervention efficacy, found that altering the timing of slurry application was effective for reducing leaching.

	Pathogens
Mean	2.2
N	18
s.d.	1.1

Table 6. Effectiveness values calculated for pathogens in slurry storage, based on study author reporting. The mean across all included studies is given, together with the total number of studies (*N*), and the standard deviation (s.d)

Policy Implications

- Existing evidence for slurry storage and changing timing of slurry application is mixed, and not always good quality, but indicates that slurry storage reduces bacterial pathogens, and that N leaching is reduced with spring slurry application as opposed to autumn.
- The evidence generally supports current policies for storing, rather than applying, slurry during autumn/winter, but further research is needed, particularly for leaching of P.

Research gaps and recommendations for further primary research

- Research that tests current legislation for slurry stores is needed to assess the effect of slurry storage on water quality. Ideally, this would take place on multiple soils representative of the UK, and would use variable slurry storage designs
- Research into impacts of changing slurry application timings on leaching of P is needed.
- There is scope to investigate the research base investigating the distance from water

bodies with regard to slurry storage and spreading to support current distance limitations built into UK guidance and legislation.

References of interest

Defra, ES0115 - Optimizing slurry application timings to minimize nitrogen losses (OPTI-N).

Arrus KM, Holley RA, Ominski KH, Tenuta M, Blank G: Influence of temperature on Salmonella survival in hog manure slurry and seasonal temperature profiles in farm manure storage reservoirs. *Livestock Science* 2006, 102:226-236.

Woodland creation

Woodland creation can potentially improve water quality by:

- Improving soil water infiltration thereby reducing water runoff and the risk of pollutants entering water sources
- Up taking of nutrients which otherwise be lost to water sources

Much of the evidence found in this review related to buffer strips composed of trees, and is therefore considered in the buffer strip section. Other woodland creation studies found were limited as most research falls outside the scope of the question investigated here, but studies investigating the wider benefits of trees for water are extensive and reported elsewhere .

What evidence was found?

Buffer strip studies with a tree component were not categorized under woodland creation, but instead under buffer strips, and so are not discussed here. Few other woodland creation studies, specific to the question, were found. The studies were quite diverse and could be divided into 3 groups:

- Studies of afforestation on former agricultural land including the AFFOREST project conducted in 3 different European countries[5].
- Studies of trees grown for biomass, including studies conducted in the UK.
- Studies of trees intercropped with a cash crop.

How diverse was the evidence?

- Most studies were conducted in Europe and measured water quality within plots
- Most studies were manipulative lasting about a year, but 2 studies lasted for almost 10 years.
- Most studies had a control or comparators. These were diverse.
- Woodland creation studies mostly measured N, whereas P, sediment and bacterial pathogen counts were each only once measured.

Limitations of the evidence

- Effectiveness was difficult to assess for the woodland creation studies due to variations in the type and design of studies and sample size was relatively small (12 studies).
- Some afforestation studies did not have a non-woodland control, but instead measured changes in water quality over different aged woodlands making it difficult to ascertain if woodland had improved water quality compared to agricultural land.
- Some biomass studies did not have a non-woodland control, but instead used a non fertilized treatment as a control.

Research gaps and recommendations for further primary research

- Although only 12 studies were recorded under woodland creation, there are likely to be studies that investigate wider water quality issues than addressed here.
- Modelling studies were excluded from the review, however they can be of particular value to woodland studies, which experimentally can take years to assess.

- Biomass, coppice or intercropping studies may be underrepresented as these were not used as search terms.
- Forest Research has recently reviewed the role of trees on wider water quality issues (many outside the scope of this review), but also includes woodland creation and buffer studies[6].

Selected references of interest/to support the findings/recommendations reported

Goodlass, G., et al., Nitrate leaching from short-rotation coppice. Soil Use and Management, 2007. 23(2): p. 178-184.

[5]Hansen K. (eds): *Literature review for AFFOREST: Planning afforestation on previously managed arable land - influence on deposition, nitrate leaching, and carbon sequestration.* 2002.

Sugiura, A., S. Tyrrel, I. Seymour and P. Burgess (2008). "Water Renew systems: wastewater polishing using renewable energy crops." Water Science and Technology 57(9): 1421-1428.

[6]Nisbet T, Silgram M, Shah N, Morrow K, Broadmeadow S: Woodland for Water: Woodland measures for meeting Water Framework Directive objectives. *Forest Research Monograph, 4, Forest Research, Surrey, 156pp* 2011.

Subsoiling (break up compacted soil layers) and controlled traffic on grasslands

The confinement of farm machinery to certain areas of a field (controlled trafficking) or the breaking up of compacted soil layers (subsoiling) by a mechanical soil treatment can potentially improve water quality by:

- Reducing soil compaction to improve soil infiltration and root penetration which may reduce the risk of runoff containing pollutants entering water courses.

Studies that directly investigate this intervention were limited, but an investigation into the evidence for the effectiveness of these interventions on related factors (such as soil infiltration) would be likely to be more effective.

What evidence was found?

There were only 5 studies obtained at full text for subsoiling that directly answered the question, and none for controlled traffic on grasslands. Soil erosion and sediment loss from plots were measured in 4 of the 5 subsoiling studies. All the studies were manipulative and used a no-subsoiling control and were conducted in North America.

Limitations of the evidence

Due to lack of sample size no measures of effectiveness were calculated for subsoiling.

Research gaps and recommendations for further primary research

There is little evidence for the direct impact on water quality of subsoiling or controlled traffic on grasslands. However, studies that measured improvements in soil water infiltration were not included in this review. It is likely that the evidence relating to the impacts of subsoiling/soil compaction on water quality could be addressed using an investigation into soil infiltration. An appropriate future question for review, may be:

"What effect does subsoiling have on soil infiltration?"

Selected references of interest/to support the findings/recommendations reported

Hamza M, Anderson W: Soil compaction in cropping systems: A review of the nature, causes and possible solutions. *Soil and tillage research* 2005, 82:121-145.

Jasa, P.J. and E.C. Dickey, Subsoiling, contouring, and tillage effects on erosion and runoff. Applied Engineering in Agriculture, 1991. 7(1): p. 81-85.

Lessons learnt from the review

The principal aim of the review was to collate and evaluate research that assessed the effectiveness of the named interventions for reducing water pollution, but as part of the process other important points have been identified that can guide future reviews and primary research.

- **Question setting**
  This review covered a wide topic area, which could be broken down into 25 different questions, as there were 5 interventions and 5 different water quality measurements. This approach allowed comparisons to be made between the different interventions and outcomes, but due to the large amount of primary research studies found, it was not possible to investigate each intervention in detail. More focused questions would enable each intervention to be investigated in detail, and allow evaluation of the factors that influence the efficacy of a specific intervention.

- **Encourage good study design when commissioning primary research**
  Future primary research should ensure that study design is rigorous and appropriate to the question. When feasible, studies should have before/after and control/intervention (BACI) designs (e.g. water measurements taken both before and after an intervention is applied, and study to have at least one control measure).

- **Encourage detailed reporting of statistics and archiving of studies**
  Reports of primary research should contain adequate details of methodology employed, of data collected, and of statistics employed. This will facilitate the reapplication of data to subsequent analyses such as meta-analysis. Once reports are submitted to Defra they should be carefully archived and made publically available.

- **Systematic maps databases of evidence**
  The systematic map database, that was created as part of the review process provides a valuable resource that can be interrogated by users interested in any subtopic areas included in the database. It can be used to find primary research, to investigate trends and patterns in the research, and identify research gaps. It should be made available and would be made more accessable with a usable interface.

- **Understand the limitations of the evidence**
  Although the review provides a generic assessment of intervention effectiveness the values derived should be interpreted within the context of the research. The evidence was based on mainly field plots, of loam soils and conducted over a relatively short period of time, and so may be subject to many limitations when applying the results to river systems. The evaluation of study designs that was used for this work was very basic. Formal meta-analyses on each intervention/outcome combination should be carried out in order to enable a more accurate assessment of intervention effectiveness.

- **Use an appropriate evidence review type**
  Evidence can be collated as a systematic review, rapid evidence assessment or systematic map. Care is needed to ensure that the question appropriately designed and focussed depending on the evidence required and the review tool to be used.