Anglian Water




Undersowing maize literature review

22 August 2022

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ADAS

ADAS GENERAL NOTES

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Where field investigations have been carried out, these have been restricted to a level of detail required to achieve the stated objectives of the work.

This work has been undertaken in accordance with the quality management system of RSK ADAS Ltd.

EXECUTIVE SUMMARY

The overall objective of this project was to review evidence from the UK, and Northern and Western Europe on the impacts of undersowing grass or other cover crop species on maize yields.

The evidence review was carried out following the key principles of a Rapid Evidence Assessment (REA) and by gathering evidence from online sources (e.g. popular farming press or organisations' websites), or by contacting organisations directly asking for their permission to share and use unpublished findings in this report.

Overall the evidence from the review is summarised as:

In terms of the environmental impacts, nitrate leaching was most frequently studied. Reductions in nitrate leaching as a result of cover crop establishment by under-sowing varied widely, with studies reporting reductions in nitrate leaching of between 18% and 58% compared to conventional practice.

Impacts of cover crop establishment by undersowing on sediment losses and surface runoff were addressed by two Defra projects; WQ0140 and SP0404. The studies reported reductions in surface runoff and sediment losses in the range of 40 % to 90 % and 60% to 85%, respectively compared to conventional practice.

The reported impacts of under-sowing cover crops on maize yields varied greatly. Studies reported either yield reductions of between 5% and 30%, no change and yield increases of up to 10% compared to conventional practice.

The evidence suggests that establishment method is an important factor in controlling the success of ground-cover establishment.

Key evidence gaps & priorities for on farm trials include:

- Field trials to understand, the longer-term impacts of under-sowing on weed & pest populations across the rotation
- Field trials to assess impacts of cover crops on nitrogen supply to the following crop
- Field trials to understand the benefits and trade-offs of different ground covers (i.e the density of ground cover) on maize yields and reduction in nitrate leaching, sediment and P losses and surface runoff across a range of sites with different levels of erosion and runoff risks.

CONTENTS

INTRODUCTION

The maize growing area in England is expanding covering 200,000 ha in 2019 (a 20% increase since 2012). Maize is established in the spring and typically harvested between late September and mid-November, when soils can be ‘wet’ which increases the risks of soil compaction by harvest machinery. Soil compaction increases the risk of surface runoff and sediment loss to surface water systems and the presence of bare soils over-winter can increase nitrate leaching losses.

Cover crops are effective at reducing risks of nitrate leaching and sediment loss to water. However, in order to be effective cover crops should typically be sown before the end of August to enable sufficient ground cover to develop before the onset of winter drainage. As maize is usually harvested too late for conventional cover crop establishment, under-sowing in the growing maize crop is an approach which can provide ground cover immediately following maize harvest. It is important that effective under-sowing management strategies are used which allow sufficient cover to mitigate diffuse water pollution (e.g. nitrate leaching, sediment and phosphorus losses) without having significant detrimental impacts on maize yields. An important challenge of under-sowing is to limit the competition between maize and ground cover at the early stages of crop growth. Equally, ground cover will require sufficient opportunity to establish before the maize canopy closes otherwise growth may be restricted due to shading.

Cover crop establishment supports the objectives of the 25 Year Environment Plan and new environmental land management schemes by reducing the risks of nutrient and sediment losses to water, aiding flood alleviation and improving soil health.

The overall objective of this project was to review evidence from the UK, and Northern and Western Europe on the impacts of undersowing grass or other cover crop species on maize yields.

1 REVIEW OF PUBLISHED EVIDENCE

1.1 Methodology

The published evidence was reviewed following the main principles of a Rapid Evidence Review (REA) https://www.gov.uk/government/publications/the-production-of-quick-scoping-reviews-and-rapid-evidence-assessments to help ensure that evidence searches were carried out following a systematic approach.

1.2 Literature search

The key search terms applied are show in Table 1 Boolean search operators were used to combine terms. The search engines used were Web of Science, Google Scholar and Defra science search. Web of Science searches were filtered by a publication date range of 2000 – 2021 and sorted by relevance.

Duplicate copies were removed before screening and the most relevant 50 papers from each search, or all papers, whichever was fewer, were taken forward for screening. In total 80 sources were screened.

Table 1. Search teams and Boolean search operators

	Key search words (AND)	
	Under-sowing terms	**Research key words**
Synonyms (OR)	‘under sown* maize’	Yield
	‘over sown* maize’	Nitrate leaching
	‘under-sown* maize’	Surface runoff
	‘over-sown* maize’	Sediment
	‘Undersown* maize’	phosphorus
	‘Oversown* maize’	‘soil structure’
		Compaction
Search Term: ‘Under-sowing terms’ (AND) ‘Research key word’		

1.3 Screening

The screening of resources was carried out in accordance with the REA guidelines with RAG (Red-Amber-Green) rankings used to assess title (screening 1) and abstract (screening 2). RAG ranking was completed based on relevancy to the review objective and the inclusion and exclusion criteria (Table 2 and 3).

Table 2. Inclusion criteria

Inclusion	Rationale
Countries – UK, Ireland, Europe, USA, New Zealand	Evidence will be included from the UK, Ireland, and from temperate cool regions as defined by the FAO Agro-climatic Zone map http://www.fao.org/nr/gaez/en/ within North Western Europe; as these are areas where growing conditions are likely to be replicable in the UK
Grey /non-peer reviewed evidence	The review will gather 'grey' literature to capture findings in Defra final reports. Defra Science, and ad hoc searches in Google will be used to search for these.
Known sources of evidence	Where evidence is already known to the review group, this will automatically be included to help improve the efficiency of this process given the time constraints

Table 3. Exclusion criteria

Exclusion	Rationale
Evidence not written in English	The research team are English speakers
Publications before 2000	To highlight most relevant up to date evidence, and ensure the review is manageable to the budget and timescales.
Theses & Books	The time frame for data extraction does not allow for evidence any larger than academic journal articles.
Crop	Corn / maize grown in USA will be excluded from the search, as this crop is typically grown in warmer climates that allow an earlier harvest and is therefore is not relevant

1.3.1 RAG screening

Sources were RAG screened in stages; the first stage was based on their title. Sources that were ranked either Green or Amber were then taken to the second screening stage where abstracts were read and assigned a RAG rank. Green and Amber sources were then taken forward to full reading and data extraction Table 4.

Table 4: Number of Web of Science and Google Scholar sources at each screening stage

Stage	Total number of papers
Screening 1 (title)	23
Screening 2 (abstract)	8
Data extraction	4

1.4 Data extraction

Relevant data were extracted from the sources by filling in fields in a data extraction spreadsheet. Sources that were not present in the initial literature search but were highlighted through personal communication or referenced in other sources were added to the data extraction database ad hoc.

1.5 Summary of Evidence

Two key studies that investigated the impact of ground cover on diffuse water pollution and crop yields in England (Table 5) were identified viz. Defra projects SP0404 and WQ0140. The experimental sites used in these studies reflect contrasting soil and agro-climatic maize growing regions in England. The studies have investigated impacts of maize growing on diffuse water pollution, soil quality and biodiversity.

Table 5: Key studies investigating the environmental impact of maize cropping in England

Study	Location	Soil type	Slope	Experimental Assessments
Defra study SP0404*	Devon and Somerset	Light or medium	3% or 8%	Yield, surface runoff, sediment losses, phosphorus (P) losses,
Defra study WQ0140	Norfolk and Devon	Light or medium	3% or 13%	Yield, surface runoff, sediment losses, P-losses, nitrate leaching, soil quality

**Also published as Environment Agency report P2-123/1 (Clements and Donaldson, 2002)*

In Defra project SP0404, experiments were carried out at two sites (North Wyke in Devon and Long Ashton, Somerset); treatments included: perennial ryegrass (under-sown by broadcasting 1 month after maize drilling), ryecorn (established post-harvest) and clover (broadcast at maize drilling). In WQ0140, at two sites (Norfolk and Devon) maize was undersown, by broadcasting either ryegrass or a biodiverse seed mix (Table 6), at the 6-8 leaf stage.

Table 6: Species composition of biodiverse seed mix, Defra project WQ0140

Species	Percent by weight	Characteristics
Black medick	20	Spring/autumn germinating, annual or perennial, fairly drought tolerant
Sainfoin	25	Spring germinating, perennial, likely to increase in year 2
Alsike clover	20	Spring/summer germinating, annual or short-lived perennial, establishes and flowers well in year 1
Crimson clover	20	Spring/autumn germinating, biennial or short-lived perennial, early flowering
Bird's-foot trefoil	10	Spring germinating, perennial, likely to increase in year 2
Musk mallow	5	Spring germinating, perennial, tolerates drought

Impacts on diffuse Water pollution

The results from SP0404 showed that ground cover established at or one month after maize drilling was more effective at reducing over-winter diffuse pollution compared to post-harvest ryecorn establishment. In summary:

- At North Wyke, under-sown ryegrass reduced over-winter runoff by *c.40*-60% and sediment losses by *c.*70%, compared to the conventional stubble treatment.
- At Long Ashton clover reduced over-winter runoff, by *c.*70-90% or by *c.*60-85% (when combined with drilling across the slope) and sediment losses by *c.*85% (when maize was drilled either along or across the slope) compared to the conventional bare stubble treatment.

Results from the Norfolk site in Defra project WQ0140 demonstrated that:

- SMN (0-90 cm) levels in November 2012 and April 2013 (Figure 1) were lower on the under-sown ryegrass (P<0.01) than both the conventional and biodiverse mix treatments, reducing the potential for NO_3-N leaching losses.
- Over-winter 2012/2013, NO_3-N leaching losses from the under-sown ryegrass treatment at 40 kg/ha N were *c.*50% and *c.*40% lower (P <0.05) than losses from the conventional and biodiverse mix treatments, respectively (Figure 3), reflecting the differences in SMN levels (Figure 1). The lower SMN levels and nitrate leaching losses from the under-sown ryegrass treatment were a reflection of N uptake by the well-established ryegrass cover (Figure 2), which reduced the amount of soil N compared with the conventional and biodiverse mix treatments.
- Over-winter 2012/2013, sediment losses from the under-sown ryegrass treatment at 440 kg/ha were *c.*70% and *c.*60% lower (P <0.01) than losses from the conventional and biodiverse mix treatments, respectively (Figure 4). The reduced sediment losses from the under-sown ryegrass treatments reflects the greater ground cover, which slowed down sediment movement, compared with the conventional and biodiverse mix treatments. Similarly, total phosphorus losses from the oversown ryegrass treatment at 0.4 kg/ha was *c*.70 % and *c*.65 % lower than losses from the conventional and biodiverse mix treatments, respectively (Figure 5)

Results from the Devon site in Defra project WQ0140 demonstrated that:

- Over-winter 2012/2013, surface runoff losses from the under-sown ryegrass treatment at 25 mm were *c.*40% lower than from the conventional and biodiverse treatments (*c.*40mm), although these differences could not be confirmed statistically (P>0.05).
- Over-winter 2012/2013, sediment losses from the under-sown ryegrass treatment at 140 kg/ha were *c.*85% and *c.*75% lower (P <0.01) than losses from the conventional and biodiverse mix treatments, respectively. The reduced sediment losses from the under-sown ryegrass treatment were a reflection of the greater ground cover, which slowed down sediment movement, compared with the conventional and biodiverse mix treatments. Notably, the reduction in sediment losses from the ryegrass treatment was greater than the reduction in surface runoff volumes.

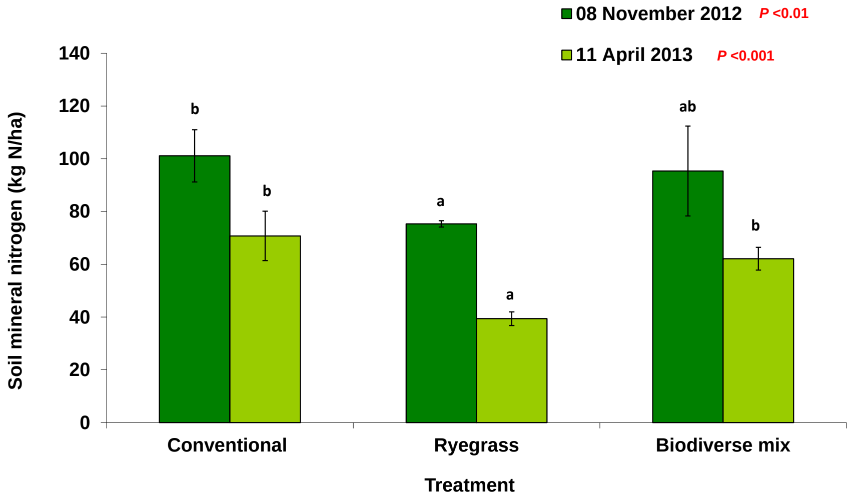

Figure 1: Soil mineral nitrogen (0-90 cm) levels measured at Fakenham in November 2012 and April 2013. Error bars represent the standard error of the mean. Bars labelled with different letters, on the same sampling date, differ significantly.

November 2012

May 2013

Strip tillage into ryegrass

Figure 2: Ryegrass ground cover at Fakenham, under-sowning June 2012, following harvest in November 2012 (left) and before (centre) and after strip-tillage (left) in May 2013

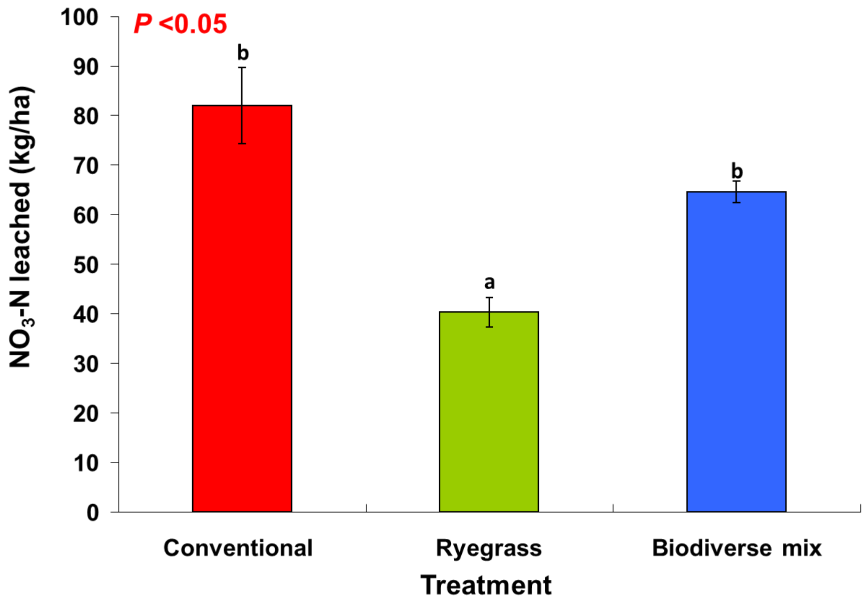

Figure 3 Nitrate-N leaching losses (kg/ha) measured over-winter 2012-2013 at Norfolk as part of Defra project WQ0140. Error bars represent the standard error of the mean. Bars labelled with different letters differ significantly (P<0.05).

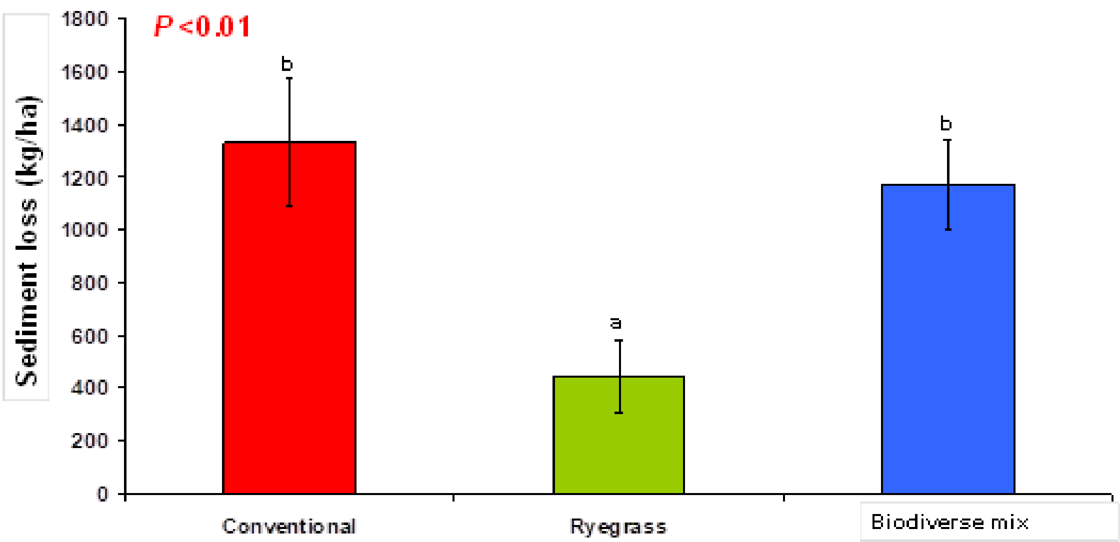

Figure 4 Sediment losses (kg/ha), measured over-winter 2012/2013 at Norfolk as part of Defra project WQ0140. Error bars represent the standard error of the mean. Bars labelled with different letters differ significantly

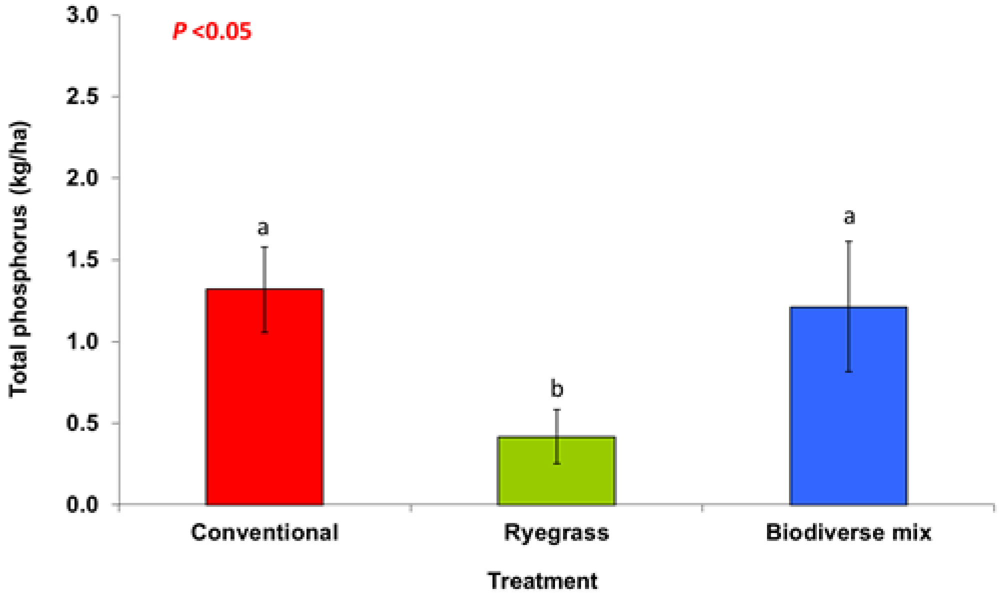

Figure 5 Total phosphorus losses (kg/ha), measured over-winter 2012/2013 at Devon. Error bars represent the standard error of the mean.

European studies

A number of studies carried out in Europe have shown that under-sowing maize can help reduce over-winter NO_3-N leaching losses, as the growing crop takes up mineral-N from the soil which would otherwise be at risk of loss through leaching. In summary:

- Schröder et al. (1996), over 6 consecutive years, investigated the effectiveness of post-harvest (mid-September to early-October) rye establishment and under-sown (Early-June) Italian ryegrass to reduce SMN and NO_3 leaching. It was found that for the first 5 years rye and ryegrass took up *c*.46 kg N ha^{-1}, with no difference between species. Nevertheless, ryegrass was consistently more effective at reducing nitrate leaching. Notably, in the last year, post-harvest drilling of rye was delayed until early-October, due to wet conditions and the crop failed, taking up <10 kg N ha^{-1}.

- At the annual MGA conference (Peterborough, 2015) Spelling-Ostergaard, presented the results from a study carried out in Denmark (Table 7) comparing the effectiveness of different under-sown species. In summary it was found that chicory was most efficient at reducing NO_3-N leaching losses. While Finke *et al.* (1999), reported that under-sowing maize (when 20 cm high) with grass can reduce the amount of residual nitrate in the soil at harvest and that early sown ryegrass was most effective.

- Whitmore and Schroder (2007) modelled nitrate leaching losses and reported that under-sowing maize reduced nitrate concentrations by 15 mg/l compared with a rye catch crop and by more than 20 mg/l compared to fallow soil.

- De Waele et al (2017) used EU-rotate-N model to simulate the impact of different management practices on overwinter nitrate leaching from two fields in the Flanders region of Belgium. Under-sowing maize with grass was compared with bare soil and no crop residue removal. Under-sowing was predicted to reduce average nitrate leaching from 63 to 47 kg N ha^{-1} on silty soils (25% reduction) and from 83 to 68 kg N ha^{-1} to on sandy soils (18% reduction).

- Wachendorf et al. (2006) reported results from a 4-year trial on sandy soil in Germany where Perennial ryegrass (L. perenne L., variety Fennema) was sown between maize rows at the 3 to 4 leaf stage. Leaching losses from the oversown treatments were reduced by 50% compared with conventional maize production.

Impacts on maize yields

In project SP0404, there was a small but not significant difference in maize dry matter yields of 4% between conventional and under-sown (at 4-6 leaf stage) ryegrass treatments.

Hans Spelling Oestergaard, presented results from a research project carried out in Denmark, at the annual Maize Growers Conference (Peterborough, February 2015), the key findings are summarised in (Table 7).

Table 7: Summary of key findings of research investigating management strategies for under-sowing maize conducted by SEDGES (Demark) presented at the annual Maize Growers Conference (Peterborough, February 2015) by Spelling Oestergaard.

Parameter	Overall finding
Cover crop species	Chicory, perennial ryegrass, Italian ryegrass, cocks foot and tall fescue might reduce maize yields if sown early (before mid-June) especially on low fertility soils. Tall fescue is best suited for early sowing (before mid-June). Chicory can be sown late because it can tolerate shading below the maize canopy. Perennial ryegrass and Italian ryegrass are best suited for late sowing. A mixture of perennial ryegrass and chicory is also suitable for late sowing.
Impact on Yield	Early or late under-sowncover crops did not significantly impact on maize yields, however there was a tendency for small reductions in maize yields, on soils with low or medium fertility. Under-sowing at the same time as maize drilling significantly reduced yields on soils with low fertility but not on soils with high fertility (e.g. previous crop grass with clover).
Methods of sowing	It was found the two best methods to ensure fast and high germination were ranked: 1. Strip sowing (3 rows) to 1-2 cm depth and a firm soil leaving 20 cm between cover crop and maize. 2. Strip sowing 3 rows with a hoe and then covering with loose soil The least effective method was: 3. Surface broadcast of seeds then covering with loose soil by hoeing.
Nitrate leaching	It was found that chicory was the most efficient at reducing NO_3-N leaching.

The results suggest that slower growing grasses such as tall fescue were best suited to early under-sowing (before mid-June) whereas chicory which is faster growing could be under-sown later with establishment before the closure of the maize canopy. Drilling 3 rows of cover crop and leaving 20 cm between the maize row and cover crop was the most effective method of establishment, i.e. it allowed a fast and high rate of germination. Overall, early or late under-sowing did not have a significant detrimental impact on maize yields, although small reductions in maize yields on low to medium fertility soils were reported.

These findings are consistent with other studies which showed that maize yields were not reduced by under-sowing grass or leguminous cover crops as long as drilling was not too early (Abdin et al. 2000; Finke et al., 1999; Kramberger et al., 2009). Hall et al. (1984) reported that corn grain yields were not significantly reduced by 'living mulches', when adequate legume suppression was obtained with herbicide treatments, whilst Garibay et al. (1997) suggested that changing the botanical composition and management of cover crops could help reduce competition for nitrogen.

Jamriska et al. (2002) reported results from three years of field experiments in Slovakia investigating the impact of under-sowing on maize yield on a loamy luvic chernozem. Three clover crops were sown under maize at two timings (5 days after sowing and at the three-leaf stage). Maize dry matter yield was reported as 528 g m^{-2} when under-sown 5 days after the maize sowing date and 662 g m^{-2} when under-sown at the three-leaf stage. Without any under-sowing maize dry matter weight was 802 g m^{-2} which suggested some reduction in maize growth on the undersown treatments as a result of competition, however no statistical analysis of the data were reported.

2 UNPUBLISHED TRIALS & DEMONSTARTIONS

2.1 Methodology

A number of demonstrations and trials have been carried out by different organisations. In some cases, the results are not easily accessible in published reports or scientific papers. Evidence has been gathered from online sources (e.g. popular farming press or organisations' websites), or by contacting organisations directly asking for their permission to share and use unpublished findings in this report.

2.2 Volume & Scope of Evidence

Demonstrations and trials have been carried out by water companies, agronomists and water trusts etc. Overall, 15 additional sources of information were obtained from field scale and small plot experiments and general observations and experiences.

2.3 Summary of Evidence

Anglian Water

Anglian Water field trials were carried out in harvest years 2018 & 2019 in North Lincolnshire on loamy sand (2018) or sandy silt loam (2019) soil. Full details of the studies and results are explained in the project final reports. Under-sowing was carried out using a bespoke drill (Figure 1) with 3 rows of grass sown between the maize rows (75 cm spacing) when maize was at the 6-8 leaf stage. The study evaluated the effectiveness of the under-sowing drill to establish ground cover and impacts of undersowing on maize yields, soil nitrogen supply, soil structural quality and over-winter nitrate leaching losses compared to conventional practice.

In the 2018 trial, maize was under-sown at the 6-8 leaf stage with either tall fescue or perennial ryegrass. It was found that:

- The under-sown ryegrass and tall fescue established well, given the dry soil conditions this was most likely aided by drilling rather than broadcasting the grass seed
- There was no evidence of differences in soil structural quality between treatments
- Maize dry matter yield from the conventional treatment was 13 t/ha, compared with 11 t/ha on the over sown ryegrass and 9 t/ha on the tall fescue treatments (15-30% reduction, respectively) (Figure 6)
- Nitrate leaching losses were reduced by 25% on the under-sown tall fescue and 50% on the ryegrass compared to the conventional treatment (Figure 7)
- Spring soil nitrogen supply was greater on the under-sown ryegrass (by c.35 kg N/ha) and the tall fescue (by *c.*10 kg N/ha) than on the conventional treatment.
- Additional costs and yield penalties associated with under-sowing resulted in reductions in gross margin of £504/ha on the ryegrass and £641/ha on the tall fescue plots, compared with conventional practice.

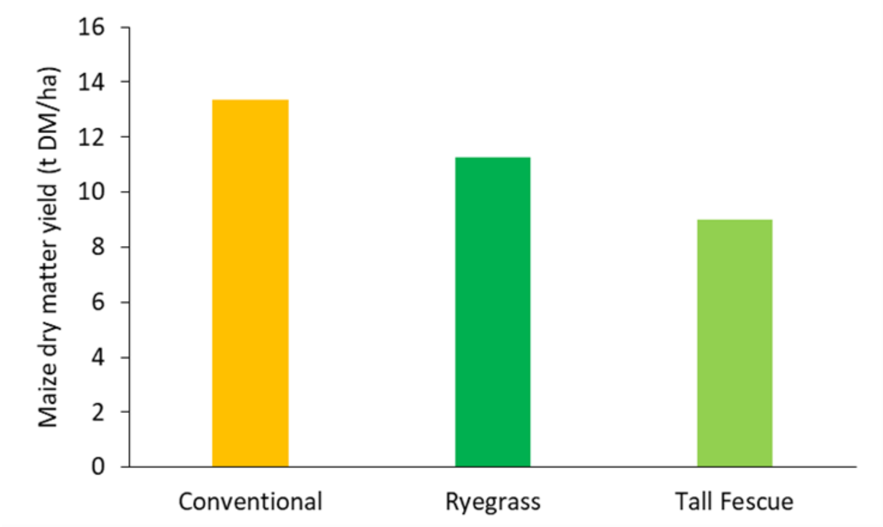

Figure 6 Maize dry matter yields, harvested on 24 September 2018.

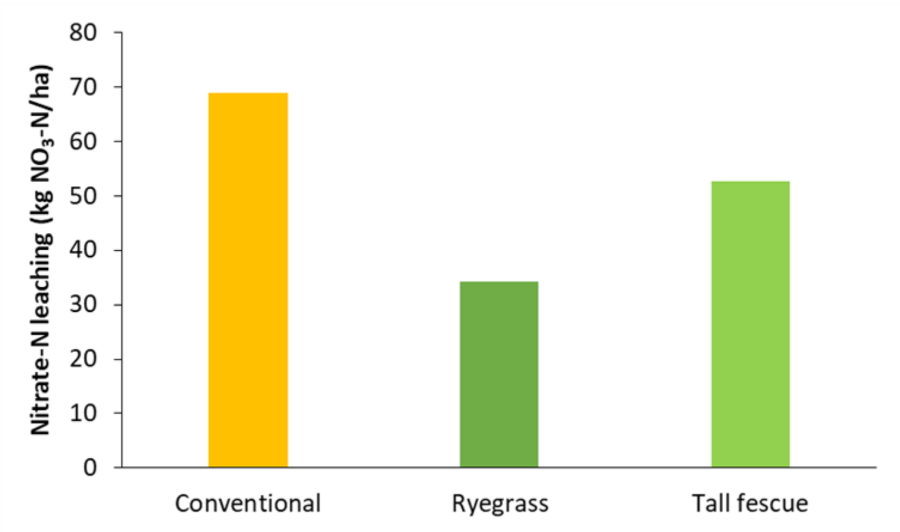

Figure 7 Total over-winter nitrate leaching losses (kg NO3-N/ha), measured from November 2018 to March 2019

In 2019 , maize was under-sown at the 6-8 leaf stage with either tall fescue or perennial ryegrass, with or without pre-emergence herbicide. It was found that:

- Under-sown ryegrass & tall fescue (without pre-emergence herbicide) germinated evenly across all plots.
- Pre-emergence herbicide had a limited impact on the establishment of ryegrass, it did result in more weedy growth which may have contributed to variability in maize yields.
- Under-sowing with either ryegrass or tall fescue had no effect (P>0.05) on maize yields, with a mean yield of *c*.17 t/ha, across all treatments.

- Heavy rainfall and wet soil conditions, delayed maize harvest until 29 October and it is likely that this limited the opportunity for post-harvest growth on the under-sown treatments, with less than 10 kg/ha N taken up by the ryegrass and tall fescue.
- Nitrate leaching losses were highest on the conventional and ryegrass treatments at *c.*130 kg NO_3-N/ha. Nitrate-N losses from the tall fescue treatment were *c.*30 kg/ha lower at 100 kg NO_3-N/ha which was equivalent to a 23% reduction compared to the other treatments.
- Visual evaluation of soil structure (VESS) assessments showed that soils were in good structural condition with no differences between treatments.

Maize Growers Association (MGA)

A technical note from the MGA (available on the AHDB website) outlines some key points known to help increase the successful establishment of under-sown grass whilst reducing negative impacts on maize yields:

- Under sow in early June when maize is at the 4-5 leaf stage
- Drilling is the most successful method of establishing ground cover – to avoid competition keep a gap of between 10 to 20 cm between the drilled ground cover and the maize rows
- If drilling early (i.e. early June) choose a slower growing grass (e.g. a fescue); if drilling later (i.e. mid-June) select a faster growing grass (e.g. perennial ryegrass or Italian perennial ryegrass)
- Recommended seed rates vary according to grass species and method and timing of establishment but are typically in the range of 15 -19 kg/ha
- Ensure that weeds are well controlled. Early treatment of small weeds (MGA advice for many years) will allow reduced chemical rates, lower herbicide costs and less risk of under-sown grass being impacted. There is no need to adjust for the type of herbicide used compared to conventionally managed maize systems.

Wessex Water & MGA

A replicated field experiment was carried out in 2020, on a medium loam soil in Somerset in which the impact of under-sowing on maize yields was compared to conventional practice. Under-sowing was carried out using a Weaving drill, with two different Italian Ryegrass varieties at two different seed rates (5 and 10 kg/ha) when maize was at the 4-6 leaf stage. The results showed that there were no differences ($P > 0.05$) in maize yields (mean dry matter yield of 16.3 t/ha) or quality (e.g. starch content or metabolizable energy (ME)) between under-sown and conventional maize treatments.

The trial was repeated in 2021, on a medium loam soil in Somerset. The results showed that maize yield was significantly greater (0.9 t/ha) when under-sown with Italian Rye Grass (sowing rate 10 kg/ha) compared to conventional practice. However, there was no significant difference in maize yields between maize under-sown with Italian Rye Grass (sowing rate 20 kg/ha) and conventional practice.

Overall, the combined results from the 2020 and 2021 trials suggested that under-sowing had no impact on maize yields.

Wessex Water

Field trials were carried out in harvest years 2016 and 2017 on a sandy loam and silty clay loam soil (2017 only) in Dorset. All trials assessed the impact of contrasting under-sowing techniques (i.e. different methods, timings and ground cover) on maize yields, soil mineral nitrogen and nitrate leaching losses (measured using porous ceramic pots) compared to conventional practice.

The under-sowing techniques compared were: 1) modified tractor front loader with mounted 6 m boomed air broadcaster and three following tines in each maize row, Technique 2) a rear mounted 6 spring tine grass harrow with rows of tines removed in order to fit between the maize rows and Technique 3) via an application of slurry to the growing maize crop through a 24 metre dribble bar, with the grass seed first mixed into the slurry via a funnel in the inlet suction pipe. Maize was under-sown at 5-7 leaf stage, with either perennial Italian ryegrass (at 12.5, 20 or 30 kg/ha), Westerwolds (at 20 or 30 kg/ha); Technique 4) using a purpose-built under-sowing drill, (6-7 leaf stage) with Italian Ryegrass at a seed rate of 25 Kg/ha.

The results suggest that under-sowing maize with Italian Ryegrass had little impact on the yield or quality of the maize crop; with mean dry mater yields of 9.6 t/ha and 14.4 t/ha in harvest years 2016 and 2017, respectively. The report acknowledges that due to the difficulties in quantifying maize yields measurements were not replicated and it was no possible to carrying out statistical analysis of the data.

Nitrate leaching measurements overwinter 2016/2017 found that:

- Under-sowing with Italian Ryegrass (at 20 kg/ha) reduced N leaching by 26 kg N/ha compared to leaving the soils bare or fallow over the winter period post maize harvest. Under sown Italian Ryegrass reduced N leaching by 18 kg N/ha compared to a post maize harvest sown cover crop.
- Italian Ryegrass under sown with an application of slurry which was retained as a cover crop reduced N leaching by *c*.19 kg N/ha and 11 kg N/ha, compared to bare soils and a post-harvest sown cover crop respectively.
- Biomass accumulation in a cover crop sown post maize harvest was lower than where the ground cover was under-sown. As a result, the post-harvest drilled cover crop was less effective at reducing nitrate-N leaching losses, (8 kg/ha reduction compared to conventional) than under-sowing (Figure 8).

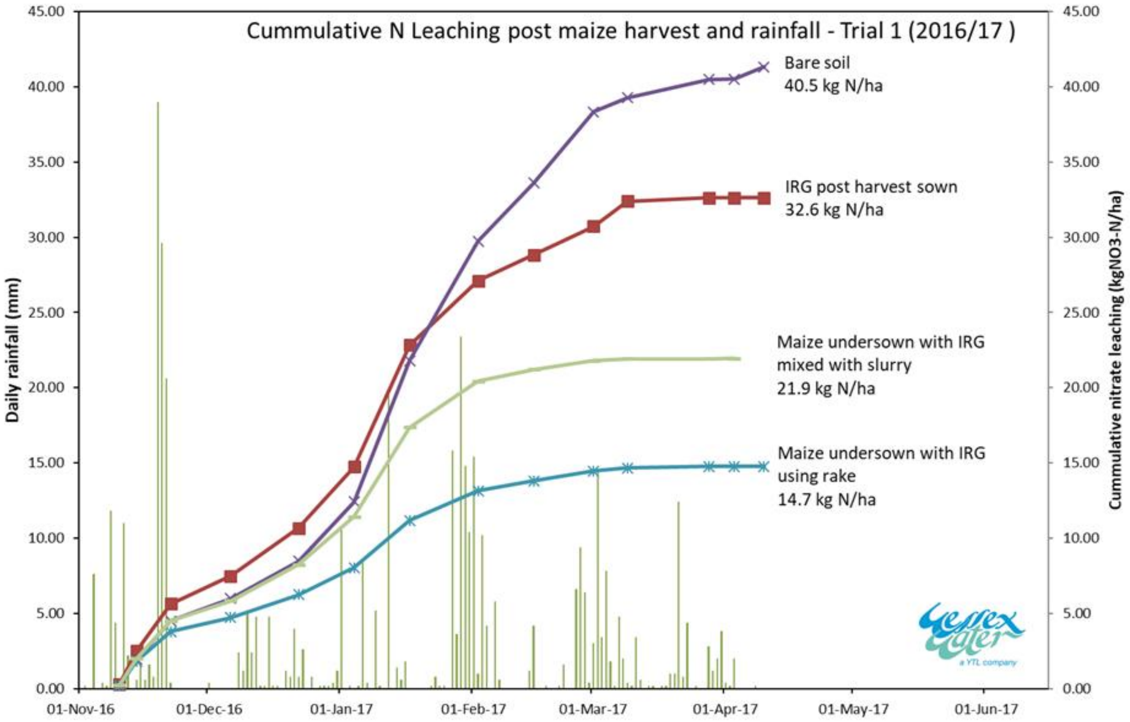

Figure 8 Shows the results from the leachate collected from porous pots over winter 2016/17.

The results from winter 2017/2018 were similar with nitrate leaching losses from the under-sown Italian Ryegrass treatment reduced by 42 kg N/ha compared to the conventional (bare soil) treatment. A post maize cover crop was less effective than under sowing at and reduced N leaching losses by only 22 kg N/ha compared to leaving the soils bare/fallow over the winter period.

In another study on a heavier silty clay loam soil, under-sowing a maize crop with Italian Ryegrass reduced N leaching by 82 kg N/ha compared to leaving the soils bare/fallow over the winter period post maize harvest.

Portsmouth Water

The impact of under-sowing maize on nitrate leaching losses was compared to conventional practice of leaving soils in stubble over-winter 2021/22. Maize was under sown at the 6-leaf stage with grass. Initial results from the trial were presented in a webinar on 25 January 2022. Preliminary results suggest that under-sowing maize with grass reduced nitrate concentrations in drainage water by 58% compared to conventional practice.

South Staffordshire Water

Field trials have been carried out in Staffordshire in the Blithe catchment on heavy soils. Tall Fescue grass was drilled at 10 kg/ha at the same time as maize using a modified Vaderstad Tempo drill. Maize rows were spaced at 75 cm). In the second year of the study, fresh maize yields in the under-sown system were 33 t/ha whilst in a nearby conventionally managed field maize yield was 29 t/ha. The study concluded that there was no detrimental effect of grass establishment on maize yields.

Agrovista

Numerous trials have been carried out between 2015 and 2019 in key maize growing regions (Cheshire, Norfolk, and Somerset) covering a range of light to medium textured soils. The trials have tested a range of different methods to establish ground cover, including different timings, ground cover species and drilling rates. The overall conclusion from these studies was that under-sowing can have a negative impact on maize yield and quality if carried out incorrectly. The key findings of the trials were:

- Tailor the under-sown mix, seed rate and timing to site conditions, particularly if under-sowing at the 2-6 leaf stage.
- When under-sowing at the 6-leaf stage, the use of faster growing Italian ryegrass drilled at higher seed rates is recommended.
- When drilling early, a mix of perennial ryegrass and late fescue is recommended (i.e. a combination), because perennial ryegrass alone is too vigorous at early maize growth stages.
- Westerwolds can die back under the maize canopy due to poor stress tolerance. Westerwolds can also be more susceptible to bolting and setting seed which then can create a weed problem in the rotation.

Agrovista provides guidance online for the suitability of their mixes when under-sowing maize: https://www.agrovista.co.uk/seeds/maize/under-sowing-mixtures-for-maize

In a Farmers Weekly article "Under-sowing trials tips and all you need to know" (6 April 2020), findings from Agrovista trials highlight that pre-emergence herbicides can negatively impact undersown grass establishment. When drilling maize and grass at the same time using a Pottinger drill; it was found that the pre-emergence chemicals held back grass growth but not to the point where seedlings were killed off, this enabled maize to establish ahead of the grass. Furthermore, results showed that under-sowing without a pre-emergence herbicide can cause yield reductions if conditions are good for grass growth, enabling it to out-compete the maize. Finally, where pre-emergence products are not used it is recommended to reduce grass seed rates".

CMG Agronomy

Trials were carried out in Norfolk during harvest years 2019 and 2020, on sandy loam and sandy clay loam soils. Different ground covers were tested (Brown Mustards, Vetch, Clover (4 species), Tall meadow fescue, Westerwold, Hybrid ryegrass, chicory &Field beans). Ground cover was established either at maize drilling, using a Pottinger combi drill or at 4-leaf stage (using Opico harrows or broadcast at 4-leaf stage). The established grass was then grazed by sheep over-winter and any remaining vegetation sprayed off with Glyphosate. The Hybrid ryegrass was able to hold sheep for 3 months. Under-sowing was found to alleviate soil compaction and improve soil water infiltration rates.

. In 2019, there was no difference in maize yields between maize+ground cover and conventional practice. In 2020, there was a 0.5 t/ha decrease in maize yields where maize was undersown.

CMG Agronomy concluded that Westerwold grass was not effective for undersowing, as it died off when the maize canopy closed. Vetches and clovers were also not effective at producing sufficient biomass or root structure. Under-sowing with grasses was most effective, but the success of establishment was dependent upon soil moisture.

United Utilities

Trials were carried out in Cheshire, in harvest year 2018 on a sandy loam soil. The ground cover treatments were Italian Ryegrass and a mix of Tall Fescue and Perennial Ryegrass. Ground cover was established either by sowing maize and grass at the same time (i.e. using a Pottinger drill), at the 4-6 leaf stage by either broadcasting seed or by drilling using a bespoke drill in order not to damage the maize crop. Limited results are available, however a summary of the advantages and disadvantages of the 3 different methods tested are presented in Table 8.

Kings Seeds and United Utilities

https://www.frontierag.co.uk/blog/under-sowing-maize-a-demonstration-event

Table 8: Summary of the advantages and disadvantages of different methods for establishing ground cover in maize. (Text taken from a United Utilities Flyer)

	At Maize Drilling	Under-sown by Broadcast seed	Under-sown by drilling
Machinery	Pottinger drill	Seed broadcaster or Fertiliser spreader	Inter-row disc drill
Timing	April/May	May/June/July	June/ July
Maize growth stage when grass sown	At maize drilling	2 – 8 leaf stage	4 -8 leaf stage
Advantages	A simple & reliable one-pass system giving early and successful grass establishment Precise grass seeding in inter-row bands	Low cost farmer DIY system using own machinery. Fast work rates. Very flexible timing, depending on weather & soil conditions.	Precise seeding by soil incorporation. Timing flexible, depending on weather & soil conditions. Tailor seed rates & varieties closer to conditions at the time.
Disadvantages	Can increase crop competition depending on species sown, seed rate and May / June weather conditions. Contractor operation. Lower work-rates at time of drilling. May potentially restrict herbicide & weed control choices.	Unreliable establishment and low success level. Patchy seed placement and within-maize row competition. May potentially restrict herbicide & weed control choices, depending on timing.	Separate contractor operation reliant on suitable soil conditions at time of sowing. Slight possibility of damage to established maize plants.

Bright Maize

Bright Seed supplied general observations rather field trials. They suggested that grass was most reliable for under-sowing and establishment was improved with good soil to seed contact by either harrowing or drilling. If drilling a 10-15 cm gap between grass and maize rows to maximise grass establishment and minimise the impact of maze yields was recommended. They suggest that under-sowing, should take place *c*.4 weeks after maize drilling with slower growing grasses recommended for early and faster growing species for later establishment, respectively.

Wye and Usk Foundation

Following field trials in harvest years 2014 to 2016, the Wye and Usk Foundation built a bespoke inter-row drill to undersow grass and have since purchased 3 additional Weaving drills. The Wye and Usk Foundation provide an under-sowing service to maize growers within its catchment in conjunction with Field Options (a local seed company). Whilst no trial data are available on the effectiveness of establishment techniques key observations from farmers were summarised in a Farmers Weekly article (6 April 2020):

- Prolonged dry weather after sowing can reduce the success of germination. This has mainly been an issue in soils with depleted organic matter levels, where water holding capacity is reduced and, therefore, seedlings are less resilient in dry conditions.
- No impact seen on maize yields.
- Where poor soil structure impacts on maize height/vigour, grass growth can be higher as more light reaches it below the maize canopy.
- Under-sown grass can provide significant quantities of grazing for the following spring.

Severn Trent Water

Trials set up in Nottinghamshire (located above the Sherwood aquifer) investigated different approaches of under-sowing maize and assessed the impacts of under-sowing on crop yields and quality and overwinter nitrate leaching losses. The trials were complex, covering a range of different seed mixes, seed rates and establishment timings. All under-sown ground cover was established using a custom-built drill or an Opico grass harrow for comparison. Data from the trials are not available however key findings were summarised in Farmers Weekly (6 April 2020):

- Seed-to-soil contact is important for germination and, on dry, sandy soils, it is important to get the grass away quickly. Broadcasting is considered too risky, and a grass harrow can dry out what little moisture there is on the surface and not all the seeds will get buried.
- The custom-built drill, like a lot of the other under-sowing rigs, uses Weaving disc coulters with press wheels. The drill worked particularly well and gave good establishment at lower seed rates.
- The drill can be set up for 75cm spacing with three rows of discs and 50cm spacing with two rows of discs.
- Under-sowing seed rates in 2019 were 10kg/ha and 15kg/ha with either Agrovista's Enviromax mix (Tetraploid late perennial ryegrass tall fescue PLUS) or Westerwolds.
- The Enviromax mix was suited to later under-sowing and persisted better through the wet autumn and winter
- The highest-yielding plot was under-sown with Enviromax at 10kg/ha (69t/ha wet at 32% dry matter) and the lowest-yielding plot was also under-sown clover and chicory (45t/ha wet at 32% dry matter). *No data were reported for the performance of under-sown maize compared to conventional practice.*

- The study reported that pre-emergence herbicide pendimethlin, did not have a negative impact on grass establishment; possibly due to the seven week interval between application and under-sowing

Reaseheath College

Trials were carried out at Reaseheath College in Cheshire, and key findings were summarised in a Farmers Weekly article (6 April 2020). The trials compared the effects of under-sowing grass at the 4-6 leaf stage (no details of method) and drilling maize and grass at the same time using a Pottinger drill. In two growing seasons, maize was found to yield better where grass sown at the same time compared to those plots where it was undersown. It was concluded that drilling the grass whilst maintaining a 15cm distance from the maize rows limited competition between grass and maize. Grass variety choice was also critical, with fescues found to have the best combination of vigour and persistence.

Hutchinsons

Trials carried out by Hutchinsons investigated the impact of pre-emergence herbicide on grass germination. The objective of the studies was to investigate the potential for residues from sulfonylurea herbicides to adversely affect grass establishment. Maize was drilled and two herbicide mixes containing mesotrione and either nicosulfuron or prosulfuron, were applied. Six weeks after drilling, maize was under-sown with a Westerwold and Italian ryegrass mix (at *c*.20 kg/ha) using a Zocon Greenseeder drill. Dry conditions in the spring resulted in the herbicides persisting longer in the soil than would be expected in wetter conditions, and observations reported some yellowing in the grass. Overall, it was observed that grass grew best where straight mesotrione was applied indicating that it was potentially the sulfonylurea content of the herbicide mixes which was having an adverse effect on grass establishment. It was highlighted that further work is required to understand the susceptibility of different under-sown grasses to damage by herbicides.

3 SUMMARY AND CONCLUSIONS

Summary of site location and characteristics

Studies have been carried out across the main soil and agroclimatic zones in England used for maize production. Defra projects WQ0140 and SP0404 were carried out on fields with slopes ranging from 3% up to 13%, with most other studies not reporting details of field slope.

Environmental Impacts

In terms of the environmental impacts, nitrate leaching was most frequently studied. Reductions in nitrate leaching as a result of cover crop establishment by under-sowing varied widely, with studies reporting reductions in nitrate leaching of between 18% and 58% compared to conventional practice.

Impacts of cover crop establishment by undersowing on sediment losses and surface runoff were addressed by the two Defra projects WQ0140 and SP0404. The studies reported reductions in surface runoff and sediment losses in the range of 40 % to 90 %, 60% to 85%, respectively compared to conventional practice.

Impacts on Maize yields

The reported impacts of under-sowing cover crops on maize yields varied greatly. Studies reported either yield reductions of between 5% and 30%, no change and yield increases of up to 10% compared to conventional practice.

3.1.1 Methods of establishment

The evidence demonstrates that under-sowing has a variable impact on both maize yields and the ability of the ground cover to mitigate over-winter NO_3-leaching, surface runoff and sediment losses. The evidence suggests that establishment method is an important factor in controlling the success of ground-cover establishment. In summary, the collective evidence highlights some key points to consider when under-sowing:

Soil conditions

- Soil moisture status and rainfall after drilling is critical for successful establishment

Method

- Drilling is more successful than broadcasting seed

Timing & Ground cover

- Recommendations for the timing of under-sowing varies, with the MGA recommending early June, when maize is at 4-5 leaf stage with, other studies recommending under-sowing at 5 to 7 leaf stage (Wessex Water) or 2 to 8 leaf stage (United utilities).
- Most studies under-sow maize with grasses, as they have been show to be most effective at reducing over-winter NO_3-leaching losses, surface runoff and sediment losses.
- When drilling early, slower growing grass (e.g. fescues) are more effective and have lower impacts on maize yields. Later drilling is best suited to faster growing varieties (e.g perennial ryegrass or Italian perennial ryegrass) which can establish before the maize canopy closes.

- Some studies report that fescue is less effective at reducing nitrate leaching losses than faster growing grass species.

3.1.2 Evidence Gaps

Key evidence gaps & priorities for on farm trials include:

- Field trials to understand, the longer-term impacts of under-sowing on weed & pest populations across the rotation
- Field trials to assess impacts of cover crops on nitrogen supply to the following crop
- Field trials to understanding the benefits and trade-offs of different ground covers (i.e the density of ground cover) on maize yields and reduction in nitrate leaching, sediment and P losses and surface runoff. Across sites with different levels of erosion and runoff risks.

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