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Research Review 101b

Updating cover crop guidance (Part B): long-term soil health impacts

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This scoping review was produced as part of the final report of a five-month project (Updating cover crop guidance – 21140093) that started in November 2024. Part A considered destruction methods. The work was funded by a contract for £30,000 from AHDB Cereals & Oilseeds.

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1. Abstract

A rapid evidence assessment (REA) was conducted to update cover crop guidance. It considered research on long-term soil health impacts of cover cropping, including cover crops grown multiple times in a rotation. It examined how cover crop species impact soil biodiversity and how various cover crop species or mixtures impact the rotation. It also identified knowledge gaps and research opportunities.

The REA considered findings from long-term experiments, other academic research and on-farm data. It included research that was conducted in the UK or in other temperate farming systems (with similar characteristics to the UK).

Searching and screening of the literature for this REA was conducted concurrently with an REA of cover crop destruction methods (Research Review 101a). It resulted in 16,168 articles screened at title and abstract for inclusion.

A total of 95 articles were included for this REA on long-term soil health impacts. Coding for this REA was carried out independently. Due to time and resource limitations, coding only used the abstracts of the included studies with no quality appraisal conducted. However, where evidence had been collated into a meta-analysis or systematic reviews, it was generally assumed that the weight of evidence was stronger than individual primary research studies. Recommendations made by the authors of the included studies should be interpreted with care.

Primary research was identified for the following long-term soil health impacts: soil biodiversity (including soil microbiome, fungi and earthworms, as well as general impacts on soil taxa); soil structure and water regulation (including water retention, runoff and erosion and general soil structure impacts); soil organic matter (including soil organic carbon and other soil organic matter findings); and nutrient retention (mainly reducing leaching). Only four primary research studies were UK-based, which mainly focused on nitrogen leaching, earthworm diversity and soil physical properties. Steering group discussions identified more UK-based advice sources.

This REA concluded that more long-term studies are required to measure impacts of cover crops on soil-health indicators. These knowledge gaps in the UK may be filled by ongoing, long-term experiments at research institutions. However, studies that purely focus on cover cropping impacts, rather than rotational impacts of systems, are required to realise the impacts of cover cropping alone. This includes more research into rotational impacts of cover cropping. More research around cover cropping strategies beyond winter cover cropping is also required.

Table 9 provides practical guidance associated with each soil health topic area.

2. Background

Cover crops are grown for a variety of reasons, and the use of cover crops is widespread on arable cropping farms (Storr et al, 2019). Cover crops provide a range of ecosystem services to the grower and to the environment, including potentially minimising soil disturbance (i.e. depending on cultivation for establishment), keeping soil covered, maintaining living roots and increasing crop diversity (all principles within regenerative agriculture). With regards to soil properties, cover crops are key for providing soil health benefits including improvements to soil structure; water infiltration; drainage; soil biodiversity and functioning; increased levels of soil organic matter; and nutrient retention.

Cover crops, in general, appear to have positive effects on most soil physical properties, but that the magnitude can be highly site and management specific (Adetunji et al., 2020; Blanco-Canqui & Ruis, 2020). Both reviews mentioned above demonstrate that whilst cover crops will improve soil properties, ensuring the correct guidance and advice given is crucial to ensuring that the maximum benefits are obtained from cover crops.

Research suggests that cover crops can help support the ecological transition of modern and intensive systems towards sustainable farming systems (for example, Quintarelli et al. 2022). Cover crops can, for example, offer wider benefits than just soil and water properties. For example, they provide resources for pollinators, with studies showing that cover crops can bolster pollinator diversity and abundance, depending on the plant species used (Bryan et al., 2021). Plant species selection can influence whether cover crops attract large numbers of generalist species or benefit fewer individuals that are of potential conservation concern (Mallinger et al., 2019). One way to improve the benefits of cover crops more widely is to use multi-species strategies with the species selected to have functional complementarity (Chapagain et al., 2020). However, there is a need to expand the research on the long-term impacts of the use of cover crops (Quintarelli et al. 2022).

AHDB provides information on cover crops online and via its Strategic Farm and Monitor Farm network to disseminate knowledge of on-farm situations around the use of cover crops. AHDB Strategic Cereal Farms network (https://ahdb.org.uk/news/how-strategic-cereal-farms-evaluate-cover-crops) have been investigating the practical aspects around using cover crops and what benefits this practice can provide from on-farm situations. The work within this network showed that cover crops can provide benefits to soil health and biodiversity without compromising cash-crop performance. They also demonstrated that cover crops can reduce nitrate leaching, when used with appropriate cultivation, and the trade-offs in management with cover crops, where establishing and destroying cover crops early would benefit spring-crop performance. However, if cover crops are maintained through spring, then a boost to beneficial invertebrates was seen.

In order to further improve the guidance provided to farmers in the UK, AHDB have identified a need for updated information around cover crops with particularly in relation to the long-term soil health benefits of using cover crops This rapid evidence assessment will look to update the state of current research, and any gaps in knowledge around long-term soil health benefits of these cover crops and of their destruction.

This report was written at the same time as the report “Updating the guidance cover crop destruction methods”. As such parts of the review were conducted together for efficient time use. This will be mentioned briefly in the relevant sections of the methodology.

2.1. Objectives of the review

The aim of this research project is to identify, collate, and describe relevant published research and current guidance and to identify potential gaps in current knowledge relating to the use of cover crops and their impacts on long-term soil health.

The scope of this research is as follows: information relevant to winter, spring-sown and summer-sown cover crops; information relevant to cover crops grown more than once in a rotation; findings from long-term UK experiments, where cover cropping has been used as part of the system and soil health indicators have been measured (if clear in the abstract); findings from on-farm or academic research where cover crops have been grown repeatedly and soil health indicators have been measured; which cover crop species impact on soil biodiversity, including to beneficial soil biology and plant pathogens; and evidence on the rotational impacts of different cover crop species or mixtures, where soil health has been measured. This review will not include the following: yield benefits; establishment and destruction methods; nutrient release to following crop; and companion cropping.

2.2. Rapid evidence assessment

A rapid evidence assessment (REA) was chosen as the method to review the literature. The method used in the development of the REA was conducted following Defra/NERC guidelines to produce Quick Scoping Reviews and Rapid Evidence Assessments (Collins et al, 2015).
The REA addressed the following primary question:

2.2.1. Primary Question

“What are the long-term soil health benefits of growing cover crops?”
The primary question is framed using population (P), intervention (I), comparator (C) and outcome (O) key elements. Table 1 shows the PICO components of the primary question.

Table 1. Components of the PICO key elements

Key element	
Population	UK arable cropping systems and temperate countries with similar farming systems to the UK (defined in inclusion criteria below) and the soil.
Intervention	Cover cropping interventions within fields used for arable farming, including cover crops grown repeatedly or more than once in a rotation, where the long-term soil health benefits of growing cover crops are investigated.
Comparator	Absence of cover cropping interventions or alternative practice to cover cropping.
Outcome	The long-term benefits to soil health of growing cover crops, including results from long-term UK experiments; findings from on-farm or academic research where cover crops have been repeatedly grown; impacts to soil health indicators or soil biodiversity; and rotational impacts of different cover crops on soil health.

3. Methods

3.1. Searching for literature

A comprehensive search, using multiple information sources, was used to capture an un-biased sample of literature. The search strategy was developed to identify both published and unpublished (grey) literature. Searches for both this REA (long-term soil health impacts) and the REA on destruction methods were conducted together. The searches were as thorough as possible within the timescale of this project. The search string was adapted to the syntax of each source searched and a record of each search made. Database and repository searches were conducted in the English language. Online sources searched to identify relevant literature are presented in Table 2.

Table 2. Online sources searched for published and grey literature

Bibliographic databases	CAB Abstracts (Harper Adams University) PubMed (Harper Adams University) Web of Science (Harper Adams University) Index to Theses Online (PhD Theses) Wiley Online Library (Harper Adams University) Cordis (EU Projects)
Organisation Websites	AHDB Defra Online Databases European Environment Agency Environment Agency (including those in devolved governments) Rothamsted Research Natural Environment Research Council CEH AAB

3.2. Search string and scoping searches

The search string was formulated in discussion with AHDB and using scoping searches to test keywords for specificity and sensitivity using the online database Web of Science. The results of the scoping search informed the final search string. Subject experts were also consulted to ensure all key and relevant terms were used within the search string. The final search string comprised of synonyms and wildcards of cover crop and intervention keywords, to ensure that results returned were not restricted. This search string was combined with that for destruction methods.
("cover crop*" OR "covercrop*" OR "catch crop*" OR "catchcrop*") AND ("soil*" OR "long term*" OR "long-term impact*" OR "rotation*" OR "crop mix*" OR "manage*")

3.3. Screening

3.3.1. Screening literature

All retrieved articles were imported into the specialised systematic reviewing software (EPPI-Reviewer6 – Thomas *et al*. 2023) and screened for relevance against the pre-defined inclusion criteria. Screening of articles was conducted at two levels (i) title, (ii) abstract. Due to the timescale of the project and the high article return of the various searches (totals included in results) it was only possible to screen articles up to abstract level. Screening for both this REA and the REA assessing destruction methods were conducted together for efficiency. This was then separated at the coding section of each review to create a separate database. Details of screening for destruction methods are included in that REA.

3.3.2. Inclusion criteria

Inclusion criteria were developed using the PICO key elements of the primary question. For the purposes of long-term soil health impacts all inclusion criteria had to be met during screening to be included in this REA.
Inclusion criteria:

- Population: UK arable cropping systems and temperate countries with similar farming systems to the UK (defined in inclusion criteria below) and the soil.
- Intervention: Cover cropping interventions within fields used for arable farming, including cover crops grown repeatedly or more than once in a rotation, where the long-term soil health benefits of growing cover crops are investigated.
  "Long-term" for the purposes of this review will be defined as: Any study that has been ongoing for 5 or more years OR any study that includes at least two cover crops in the rotation separated by at least one year or one cash crop rotation.
- Comparator: Absence of cover cropping interventions or alternative practice to cover cropping.

- Outcome: The long-term benefits to soil health of growing cover crops, including results from long-term UK experiments; findings from on-farm or academic research where cover crops have been repeatedly grown; impacts to soil health indicators or soil biodiversity; and rotational impacts of different cover crops on soil health.

Exclusion criteria:

- Outcome of studies: Studies with outcomes including Yield benefits, establishment and destruction methods, nutrient release, and companion cropping, will not be included.
- Geographical: Studies in climate zones that are not temperature
- Farming systems: Studies in farming systems not comparable to the UK
- Date: No date restrictions were applied
- Language limitations: English language only

3.3.3. Coding literature

All included literature was catalogued in a searchable database, containing key information (metadata) for each study/ review in a standard format. The database will be used to describe the extent of research regarding both primary questions and identify knowledge gaps. The depth of detail of coding was agreed with AHDB.

Recent systematic reviews or meta-analyses will be used to summarise topic areas where appropriate, as these types of reviews are considered more comprehensive and reliable than individual studies (or primary research).

3.3.4. Critical appraisal

This review did not critically appraise the included research. Recommendations made by the authors of the included studies should therefore be interpreted with care.

3.3.5. Meta-data coding

Table 3 shows the coding descriptions from which meta-data was extracted from all eligible primary research studies (abstract only), to provide detail about the article the study appears in (i.e. author, title, year, publication type, etc.) and more in-depth detail of each study considering PICO elements and study details (i.e. trial design type, length of study, etc.). Meta-data extracted is presented as a searchable Excel database.

Table 3. Coding descriptions for primary research studies

Category		#	Coding description
Bibliographic information		1	Unique article ID
		2	Author(s)
		3	Title
		4	Publication date
		5	Publication type
		6	Reference type
		7	DOI number
Study background		8	Location
		9	Latitude
		10	Longitude
		11	Article topic
		12	Sub-topic
		13	Climate zone (Köppen-Geiger)
Study details	Population	14	Population (soil, wider environment)
	Intervention	15	Cover crop
		16	Cover crop rotation
	Comparator	17	Comparator (control or alternative practice)
		18	Treatment category
		19	Treatment(s)
		20	Control(s)
	Outcome	21	Measured outcome (what effect is measure)
		22	Measured outcome category
	Study design	23	Soil type
		24	Farming system
		25	Study design
		26	Study period
		27	How many times the cover crop was implemented
		28	Replication
		29	Scale
		30	Author reported effects
		31	Measured outcome description
Notes		32	Any other notes

3.3.6 Description of study

Due to the timescale of this REA priorities of analysis will be given to studies that are perceived as more robust. Where possible, meta-analysis will be used to report information about each topic, as these are seen as more robust research. Where only one meta-analysis or no meta-analyses have been conducted systematic reviews and then narrative reviews will be used. Meta-analyses follow a strict methodology which statistically analyses information gathered from the articles included, summarising the existing research in a quantitative manner. Systematic reviews summarise existing literature in a structured manner, only sometimes statistically analysing information gathered. These reviews follow a strict methodology and often describe the state of the literature and any knowledge gaps. Both meta-analyses and systematic reviews include study quality assessments. Narrative reviews give a broad overview of the existing research, often not following a strict methodology and can be subjective. Narrative reviews do not include statistical analysis and rarely including a study quality assessment. Therefore, without quality appraisal, it is assumed that topics that have a meta-analysis have more robust conclusions than narrative reviews.

Where none of the above are available, or there is a small number, manipulative studies will be used to assess results. These studies are assumed of higher quality to correlative, monitoring and sampling studies. Manipulative studies are those that are set out with replicates and are a plot-based trial. Correlative studies compare results from two farms to each other, for example. These studies merely see any correlation between practices. Monitoring studies are when sampling is conducted several times on one farm looking at the temporal change in the selected measured outcome. Sampling studies are those in which conclusions are drawn from one sampling session.

4. Results and Discussion

4.1. Summary

The combined search results for both long-term soil health and destruction methods – yielded a total of 30,041 results. Of these, 13873 duplicates were removed, and 16,168 articles were screened at title and abstract level for inclusion. Priority screening was adopted to ensure rapid assessment of the academic research, and this was capped at screening of 5600 articles due to low (one inclusion per 100 articles) inclusion rates.

A total of 95 articles were included for the topic of cover crops and long-term soil health impacts. These included 45 primary research articles, 22 meta-analysis, six systematic reviews, two quantitative reviews (reviews with a statistical analysis) and 20 general literature reviews.

Information was only extracted from the abstract of these articles and categorised appropriately. Both primary research and review authors reporting on long-term soil health usually suggested a positive effect of cover crops on a variety of soil health indicators (79 articles reported a positive effect in the abstract). 22 articles reported mixed, no or little effect of soil health indicators, with 5 articles reporting a negative effect on soil health indicators. These findings ranged in topic from soil biodiversity (e.g. soil microbial communities, earthworms, etc), soil structure and water regulation (e.g. runoff, erosion, etc), soil organic matter (e.g. soil organic carbon, soil N content, etc) and nutrient retention (e.g. reducing leaching). However, none of the articles were quality appraised, so these trends should be interpreted with care.

4.2. Weight of evidence for long-term soil health

For this review, no quality appraisal of included studies was carried out, but where evidence has been collated into a systematic review or meta-analyses, it is generally assumed that the weight of evidence is stronger than by considering individual primary research studies. Although even meta-analyses and even systematic reviews may be subject to bias, this is likely to be reduced when compared to traditional literature reviews. Where systematic reviews or meta-analyses were not available on a sub-topic area, we have collated author findings from primary research, but these must be interpreted with care as studies have not been quality appraised.

The sections below highlight where meta-analyses and systematic reviews have been carried out as this may imply a greater weight of evidence. Where these were not available or limited, narrative reviews and in some cases, primary research has been highlighted.

4.3. Long-term soil health

4.3.1. Soil biodiversity

For soil biodiversity there were four meta-analysis, two systematic reviews and six literature reviews found within the rapid evidence assessment.

Three meta-analysis and one systematic review focussed on soil microbiome and one meta-analysis on arbuscular mycorrhizal fungi. The other systematic review focussed on a wide range of soil biodiversity taxa (bacteria, fungi, nematodes and earthworms).

The six literature reviews covered topics from earthworm abundance, soil microbial activity and soil microorganisms.

Table 4. Author reported effects from the reviews on soil biodiversity

Organism	Number of reviews	Author reported effects
Soil microbiome	Meta-analysis: 3 Systematic reviews: 1	Cover crops enhance soil microbial community abundance (Kim *et* al. 2020; Muhammed *et al*. 2021a; Liu *et al*. 2024). One meta-analysis demonstrated that cover crops significantly increased parameters of soil microbial abundance, activity and diversity by 27%, 22% and 2.5% respectively (Kim *et* al. 2020). The systematic review echoed these results with more than half the studies included (22) report higher soil microbial biomass in soils with winter cover crops compared to bare fallow within the rotation (Morales *et al*. 2021).
Fungi	Meta-analysis: 1	Less intensive tillage and winter cover crops increased arbuscular mycorrhizal fungi (AMF) colonisation of the summer cash crop roots by 30%. Key variables were type of cover crops and type of alternative tillage. Several studies showed changes in diversity and community composition of AMF with cover crops but not consistent (Bowles *et al*. 2017).
Earthworms	Narrative reviews: 1	Authors report that earthworm abundance was increased in 13 out of 22 articles reviewed, and biomass was increased in 5 out of 10 articles reviewed. There were also mixed results on diversity of earthworms with cover crop use (Blanco-Canqui, 2022).
All taxa	Systematic reviews: 1	Cover crops showed neutral to positive effects for the abundance of all functional groups across all taxa (Cozim-Melges *et al*. 2025). Particularly, this systematic review demonstrated that all studies included had a positive impact on nematodes species richness, as well as a positive impact on epigeic, endogeic and anecic earthworms (Cozim-Melges *et al*. 2025).

Nine articles of primary research studied cover crop long-term impacts on soil biodiversity. The studies ranged from five to ten years of experimental investigation. Most of the primary research focussed on soil microbial activity (seven articles), with the remaining articles focussing on earthworms (two articles). Additional information of note to add to the findings of meta-analysis and systematic reviews above were as follows:

- The proportion of time with cover crops during a 10-year rotation had a much stronger impact on soil microbial diversity and soil multifunctionality (Garland et al. 2021).

No primary research on soil biodiversity mentioned soil type in the abstract.

4.3.2. Soil structure and water regulation

For soil structure there were four meta-analysis, two systematic reviews, one quantitative review and 12 literature reviews found within the rapid evidence assessment. Of the meta-analysis, two on runoff and erosion, three on water retention (including drainage – i.e. groundwater recharge – and infiltration rate). The two systematic reviews and one quantitative review focussed on general soil structure (with one systematic review also mentioning runoff and erosion). The nine literature reviews covered topics from runoff and erosion to general soil structure, such as compaction and fertility.

Table 5. Author reported effects from the reviews on soil structure

Structure feature	Number of reviews	Author reported effects
Water retention	Meta-analysis: 3	Drainage: Cover crops reduced drainage by a mean effect size of 27mm compared to that of bare soil. However, there was no determining factor to explain the variability of water drainage reduction (Meyer *et al*. 2019). The other meta-analysis reported that whilst there was a positive effect in reducing leaching, there no demonstrated effect on water drainage (Nouri *et al*. 2022). Infiltration rate: Whilst not the focus of this meta-analysis, infiltration rate with the use of cover crops was reported to increase by 34.8% (±7.7%) (Basche & DeLonge, 2019).
Runoff and erosion	Meta-analysis: 2	The first meta-analysis focussed on conservation management practices that could decrease runoff and erosion. This article reported that cover crops were associated with the greatest reductions in both runoff and erosion compared to other conservation practices (Du *et al*. 2022). The second meta-analysis focussed on a similar topic but in western Europe, and specifically comparing

		conservation tillage, tied ridging and winter cover cropping. This article reported that winter cover crops reduce runoff by 68% and soil losses by 72% compared to bare soil.
	Systematic review: 1	Blanco-Canqui *et al*. (2015) reported in a systematic review that cover cropping decreased runoff and sediment loss, as well as decreasing wind erosion potential.
	Narrative review: 1	Blanco-Canqui (2018) reported that cover crops were highly effective at reducing runoff and sediment losses.
Other (e.g. structure, compaction and soil health indicators)	Systematic reviews: 2	Systematic reviews of soil structure reported that cover crops show strong evidence of improving soil structure and health (Blanco-Canqui *et al*. 2015; Hao *et al*. 2023).
	Quantitative reviews: 1	The quantitative review focussed on the ecosystem services of cover crops and reported that cover crops benefitted ecosystem services in most cases. Including: Erosion control; water quality regulation; soil moisture retention; etc) (Daryanto *et al*. 2018).
	Narrative reviews: 9	A summary of the narrative reviews of the effect of cover crops on soil structure report that cover crops can: reduce compaction; improve soil health and soil health indicators; improve soil physical properties; and reduce bulk density (how these indicators were measured was not mentioned in the abstract).

10 articles (some had multiple sub-topics) of primary research were included studying cover crop long-term impacts on soil structure. The studies ranged from five to forty years of experimental investigation. The primary research focussed on soil physical properties such as soil quality (indicators used to qualify this not mentioned in the abstract), bulk density, etc (10 articles) and 1 article focussed on humic substances. The primary research reported similar findings to the meta-analysis and reviews above, with generally cover crops improving soil structure.

Articles that mentioned a specific soil type in the abstract reported that:

- Cover crop inclusion did not affect macro-aggregates at 1-2mm but decreased at 8-16mm. They also increase stabilisation of large-macroaggregates (Qi *et al.* 2022). Study conducted in Denmark on a **sandy loam** soil.

- Generally, in combination with reduced tillage, cover crop use improved soil structure and soil quality index (using 19 soil health indicators – not mentioned which indicators in the abstract) (Bhardwaj *et al*. 2011).

4.3.3. Soil organic matter

For soil matter there were 12 meta-analysis, three systematic reviews, two quantitative review and 12 literature reviews found within the rapid evidence assessment. Of the meta-analysis, 11 focussed on or mentioned soil organic carbon (SOC), one on soil N content and one on total microbial necromass. Two systematic reviews and one quantitative review focussed on SOC. The remaining systematic review and quantitative review focused or mentioned more generally on soil organic matter (SOM). The 12 literature reviews covered topics from SOC, soil enzymes and soil N content.

Table 6. Author reported effects from the reviews on soil organic matter

Soil Matter	Number of reviews	Author reported effects
SOC	Meta-analysis: 11	General findings from the meta-analysis showed that the use of cover crops had a positive impact on soil organic carbon (10, with one reporting no short-term effect on SOC, but a positive effect long-term on SOC (Crystal-Ornelas *et al*. 2021)). However, one meta-analysis demonstrated that over an average of 15 years, cover crops had no effect on SOC (Jordan *et al*. 2022). Outcomes stated in the meta-analysis show that SOC shows an increase of anywhere between 7.3% (Joshi *et al*. 2023) to 15.5% (Jian *et al*. 2020), depending on the study. Another demonstrated that the use of cover crops caused an annual change in SOC stock on average of 0.2Mg ha^{-1} yr^{-1} for up to 54 years of use (Poeplau & Don, 2015).
	Quantitative review: 1	The quantitative review mainly focussed on wider implications of cover crops in cereal rotations, but state one of the key findings to be the positive effect of cover cropping on soil carbon is potentially offset by increased GHG emissions (Junod *et al*. 2024).
	Systematic review: 2	Both systematic reviews regarding SOC demonstrated increase SOC stocks from the use of cover cropping. In general, the narrative reviews suggest that SOC is improved using cover crops. One narrative review

	Narrative review: 8	suggests that the use of cover crops does not have a long-term effect on soil carbon organic stocks (Chaplot & Smith, 2023).
Soil N content	Meta-analysis: 1	The only meta-analysis conducted on soil N content suggested that soil total N (0.25 Mg N ha^{-1} yr^{-1}) accumulated fastest during the first three years of cover crop implementation and declined thereafter (Hu *et al*. 2022). *This study was conducted in an orchard, so results for arable should be interpreted with caution.*
SOM & other findings	Meta-analysis: 1	The meta-analysis focused mainly on total microbial necromass (which play a key role in soil carbon sequestration and nutrient cycling). This study found that cover crops raised the total microbial necromass by 25.3% and mitigated negative effects of tillage (Liu *et al*. 2024).
	Quantitative review: 1	The quantitative review investigated the ecosystem services of cover crops. Daryanto *et al* (2018) suggested that cover crops are beneficial to ecosystem services in more cases (including for SOM).
	Systematic review: 1	Cover crops increase soil microbial biomass carbon, nitrogen and SMBC/SMBN ratios by 39%, 51% and 20%, respectively. Non-legume cover crops enhanced these compared to legume cover crops. Effect was higher in medium-textured soils compared to coarser or fine soils for SMBN and the ratio, in contrast SMBC was higher in coarser-textured soils (Muhammad *et al*. 2021b).
	Narrative review: 4	In general, narrative reviews suggest a positive effect of the use of cover crops on soil organic matter.

33 articles of primary research were included studying cover crop long-term impacts on soil organic matter. The studies ranged from three to forty-eight years of experimental investigation or practice in place. The primary research mainly focused on soil organic carbon, with a few studies on soil nitrogen and organic matter in general. The primary research reported similar findings to the meta-analysis and reviews above, with generally cover crops improving soil organic matter. However, the longest experiment in the soil organic matter category (up to 48 years) suggested that the

effects of cover crops on soil organic carbon were not significant. This was one study, with other items of primary research suggesting similar positive results to the meta-analysis.

Articles that mentioned a specific soil type in the abstract reported that:

- The effects of cover cropping on a **clay loam** demonstrate no significant effects on soil organic carbon up to 48 years (Yang *et al*. 2004).
- On a **sandy loam**, long-term cover crops had significantly greater soil organic carbon and total nitrogen stocks (22% and 26%, respectively) compared to no cover crop (Peng & Van Eerd, 2024).

4.3.4. Nutrient retention

For nutrient retention (namely focused on leaching), three meta-analyses, one systematic review and six narrative reviews focussed on or mentioned nitrate leaching (N leaching).

Table 7. Author reported effects from the reviews on nutrient retention

Structure feature	Number of reviews	Author reported effects
Leaching (mostly N leaching)	Meta-analysis: 3	Globally, the use of cover crops reduced nitrate leaching by 69% compared with fallow (Nouri *et al*. 2022). This meta-analysis also stated that cover cropping reduced N leaching on conventional systems by 63%, no-tillage systems by 50% and reduced tillage systems by 38%. Two meta-analyses reported that non-legume cover crops reduced N leaching loss (Valkama *et al*. 2015 – by 50%; Thapa *et al.* 2018), whilst legume cover crops did not diminish the risk of N leaching (Valkama *et al*. 2015). Thapa *et al*. (2018) further reported that non-legume with legume cover crop mixes reduced N leaching as effectively as sole non-legume cover crops (and better than legume-based cover crops).
	Systematic review: 1	Abdalla *et al*. (2012) conducted a critical review of the impacts of cover crops, with N leaching being a major investigative factor. They found that the use of cover crops significantly decreased N leaching.
	Narrative reviews: 6	Narrative reviews reported that in general cover crops were effective in reducing leaching (Meisinger *et al*. 1991 – 20-80%; Aronsson *et al*. 2016 – 43%; Blanco-Canqui, 2018).

		Grasses and brassicas are two to three times more efficient than legumes in reducing N leaching (Meisinger *et al*. 1991). N leaching reported for all cover crops ranged from 62% increase after red clover on a **clay soil** to 85-89% reduction with perennial ryegrass on **sandy soil** in Denmark (Aronsson *et al*. 2016). This same review reported that P leaching ranged from an 86% increase to a 43% decrease with various cover crops. Other, more general narrative reviews (Sharma *et al*. 2018; Wanic *et al*. 2019; Yousefi *et al*. 2024), all concluded that the use of cover crops prevents, limits or decreases N leaching.

15 articles of primary research were included that investigated the long-term effects of cover crop use on leaching. The studies ranged from three to 28 years of experimental investigation or practice in place. All the studies sampled N leaching, with two also investigating P leaching (one of which also investigated K leaching – Noberg & Aronsson, 2024). Most studies suggested that the use of cover crops generally reduced leaching, with non-legume cover crops and mixtures performing better than standalone legume cover crops.
Articles that mentioned leaching in the abstract reported that:

- On **sandy soil**, fodder radish showed significantly lower leaching compared to other cover crops and winter rye had the highest leaching (Vogeler et al. 2023). Four-year manipulative study.

4.3.5. UK Studies

Only four studies were found during screening that were specifically UK based for long-term soil health. These studies ranged from two in the late 1990s, one in 2017 and the other in 2023. They were conducted over eight, five, eight and 12 years, respectively. They were all monitoring studies, and the two trials in the 1990s had their soil type stated in the abstract (one on a heavy clay soil and one on a sandy soil).

The two studies in the late 1990s demonstrated that: less nitrate was lost when winter cover crops were used compared to winter fallow (Catt *et al.* 1998); and, similarly, cover crops decreased N leaching, but over seven years cover crops decreased N concentration (Shepherd, 1999).
More recent studies focused on long-term effects on soil biodiversity and soil structure. Stroud *et al* (2017) investigated the use of oilseed radish to enhance burrowing earthworms. This study found that over eight years of trials, cover cropping with oilseed radish had no significant effect on *Lumbricus terrestris* midden counts.

Martlew *et al*. (2023) investigated the long-term impacts of repeated cover cropping and cultivation approaches on subsoil physical properties. This study focused on the repeated use of brassica cover crops over a 12-year trial period. Their experiment demonstrated that cover cropping combined with shallow cultivation results in lower penetration resistance and increases in soil moisture in the subsoil. Benefits of cover cropping were not observed when higher intensity and deeper cultivation was used.

Following a steering group discussion regarding additional sources, a further search was made specifically on UK based studies within research institutes or for specific authors (e.g. NIAB) that were not found during the initial grey literature screening.

Table 8. Ongoing long-term trials

Organisation/study	Experimental results
NIAB/ New Farming Systems (NFS)	Long term experiment being conducted on a sandy loam soil established in 2007. The research consists of a series of large scale, long-term, replicated experiments. This experiment evaluates a range of cover cropping approaches (long-term clover bi-crops, brassica and legume mix based cover crops). Results from this project have demonstrated improved soil characteristics associated with the use of cover crops. However, the range of cover cropping management differ in their requirements (Stobart & Morris, 2013, Stobart & Morris, 2014).
The James Hutton Institute/Centre for Sustainable Cropping (CSC)	The CSC was established in 2009 to test the long-term impacts of an integrated cropping system on whole-system sustainability. Part of this experiment included the use of winter cover crops. Results from the experiment demonstrated that soil carbon content could be increased from around 2% to 4% in 6 years with sustainable practices including cover cropping.
Agrovista (agrovista.co.uk/lamport-agx-2023)/Project Lamport	Project Lamport was established in 2013 to investigate solutions to help control severe blackgrass. Measures taking in 2023 demonstrated the beneficial effects of reduced tillage and cover crops on soil organic carbon after five years of study on the silty clay loam soil. After five years the no-till/ cover crop plots had significantly higher levels of soil organic matter (5.3%) than other systems (apart from the field margin plots – 8.6%). Overall, no-till/ cover crop treatments also had significantly increase soil carbon stocks at 15-30cm depth.

Rothamsted Research/ Large-scale Rotation Experiments (LSREs)	Established at Broom's Barn in 2017 and Harpenden in 2018 investigating one of three rotations: a three-year rotation aiming at short economic return; a five-year rotation with greater diversity of crops (including cover crops); a seven-year rotation for increased environmental sustainability (including cover crops and two-year ley). This was coupled with contrasting soil cultivation treatments. Results are still coming out from this trial.

4.4. Knowledge gaps and future research

An REA of the current research on cover crop destruction methods was conducted alongside this REA on long-term soil health impacts. However, what was not included within long-term soil health was what impacts different destruction methods have on long-term soil health. A recommendation for future research would be to assess the research regarding each type of destruction method and their impacts on long-term soil health (e.g. grazing impacts on soil compaction, nutrient retention).

The first major key knowledge gap, as identified in some meta-analysis and systematic reviews, is still the need for more long-term studies to examine the effects of cover crops, especially on soil physical properties (Hao *et al*. 2023; Van Eerd *et al*. 2023). With results yet to come out from long-term trials at Rothamsted Research, and more information to potential come from other long-term trials involving cover crops in the UK, this knowledge gap may be fulfilled in the next few years. However, long-term trials investigating solely focused on cover cropping practices, rather than systems approaches, may be required to see the effects of cover cropping alone.

A further knowledge gap identified by this REA (with the caveat that this information was obtained from abstract only), is the seeming lack of research into any other cover cropping strategy than winter cover cropping. This might be due to the fact information was only obtained from the abstract so was not picked up during screening. Further recommendations for cover crop type would be to either conduct a more in-depth systematic review specifically investigate cover cropping seasonal strategies, or to conduct research that compares the long-term effect of cover crops sown at different periods of the year. This could be key research for future guidance on cover cropping as articles included in this REA generally study a cover crop sown at a single point in the year compared to a bare fallow or soil.

Further research that is recommended to be conducted (or investigated in a specific systematic review) is to determine rotational impacts of cover cropping. This was within the scoping of this REA, however, studies included did not mention rotational impacts of using cover crops. This could be that this is a true knowledge gap, or it was not mentioned in the abstracts of the primary research and therefore not included in this REA.

pH is one of the components of AHDB's soil health scorecard (ahdb.org.uk/knowledge-library/the-soil-health-scorecard), however, pH was not mentioned within the abstracts of the research included in this REA. This could be because pH was taken as a standard in various experiments and not considered a key component of cover crop impacts on long-term soil health. Further research could concentrate on pH alone as this may have been measured as part of experiments included in this REA but not mentioned in the abstract.

Two final recommendations for further research (these could have been explored in the included research but left out of the abstract information) are regarding how the soil health indicators were measured and research specifically on plant pathogens. Neither of these were mentioned in the abstracts of the research included in this REA. How the soil health indicators were measured is important as this will give a better understanding of the robustness of information provided by the primary research, and the depth to which data was gathered in these experiments. Plant pathogens are also important for subsequent crop health, therefore research conducted on how cover crops impact soil-borne plant pathogens is vital research to ensure the best management advice is offered to farmers to best protect subsequent crops from plant pathogens.

4.5. Practical guidance

Table 9. Practical guidance associated with each long-term soil health category

Category	Practice	Information
Soil biodiversity, soil structure and soil organic matter	Cover cropping and cultivation (all cover crop species)	To see increased benefits of cover cropping, shallow or no-till cultivation would improve soil biodiversity, soil structure and soil organic matter. This was demonstrated in the literature and UK-based studies (Martlew *et al.* 2023; Centre for Sustainable Cropping – James Hutton Institute; Project Lamport – Agrovista).
Soil organic matter and leaching	Cover crop type (legume/non-legume cover crop species)	Legume cover crops tend to improve soil organic carbon and nitrogen in comparison to non-legume cover crops. However, non-legume cover crops reduced nitrogen leaching better than legume cover crops. This is shown in one experiment where vetch had the highest effect on soil nitrogen (five-year trial period, 12 years in rotation). Whereas ryegrass and rye had little to no effect on soil nitrogen (Kuo *et al*. 2001). With leaching, a meta-analysis showed non-legume cover crops reduced nitrogen leaching by 50% on average. Whereas legume cover crops did not diminish the risk for nitrogen leaching (Valkama *et al*. 2015).
Soil biodiversity	Time in rotation of cover crop (all cover crop species)	Garland *et al*. (2021) demonstrated in a 10-year experiment that the longer cover crops were present, the stronger the beneficial impact on soil functioning and microorganisms.

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