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Nutrient release from cover crops Task 1: Quick Scoping Review on the evidence and methodologies for estimating and predicting timing and amount of nutrients released from cover crops

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CONTENTS

1. Abstract

The inclusion of cover crops in conventional farming systems is encouraged as a method to control soil erosion and weeds, improve soil moisture and nutrient content, and reduce soil compaction and losses of nitrogen (N) to the environment. The legacy effect of cover crops on subsequent cash crops in the rotation (i.e., the immediately following crop and second following crop) is more uncertain, in particular the amount and timing of the nutrients released from cover crops and the availability of these nutrients to the following cash crop(s). An improved understanding of nutrient release from cover crops into the soil and the availability of these nutrients to the subsequent cash crop(s) will help farmers better account for nutrient recycling and can be used to inform nutrient management plans when calculating manufactured fertiliser requirements.

The overall aim of this project is to collate and review all existing evidence to inform the feasibility of creating a Decision Support Tool (DST) to help UK farmers predict nutrient release following the use of cover crops and provide recommendations for future development of the tool. This report covers Task 1 of the project.

The Task 1 quick scoping review (QSR) evaluated the scope and volume of the existing evidence base on the amount and timing of nutrient release from cover crops, the methodologies and tools available to do this, and identified key knowledge gaps. The QSR evaluated data from 51 pieces of evidence (including peer-reviewed and grey literature) and concluded the following:

- Evidence on nutrient release from cover crops in temperate climates is dominated by measurements from single and multispecies winter cover crops, rather than summer or autumn cover crops, with 30 % of all measurements originating from field sites in the UK.
- Evidence on cover crop residue characteristics (i.e. N% & C:N ratio) is primarily for aboveground biomass, with little data available on belowground biomass such as roots and nodules.
- Data on N return to soil from cover crop residues was more abundant than data on phosphorus (P) and potassium (K) return to soil.
- Data on the availability of N from cover crop residues to the following cash crop was more abundant than data on P availability to the following cash crop, with no data on the amount of K available to the following cash crop.
- It was more common for measurements of nutrient release to the soil to be reported than predictions of nutrient release to the soil.
- It was more common for measurements of nutrient availability to the following cash crop to be reported than predictions of nutrient availability to the following cash crop. The amount of N available to the following cash crop ranged between 0 -120 kg N/ha, and was most frequently around 0-30 kg N/ha; with UK measurements not exceeding 81 kg N/ha.
- In the UK, more measurements found the majority of N in cover crop residues to be released immediately after cover crop destruction (e.g., within several days). The most

common time for the majority of nutrient release to occur was within several days, with this occurring in 30 % of the observations as a whole, but rising to nearly 100 % in the available UK data.

The findings from the QSR highlight that the evidence base currently focuses on N release from winter cover crop residues, with measurements of P and K and overall nutrient release from summer and autumn cover crops lacking. Future research should consider both aboveground and belowground cover crop residues, and consider biomass quality (i.e., N%, C:N ratio) with quantity and nutrient release, as this information can be used to increase the accuracy of nutrient supply DSTs.

2. Introduction

The inclusion of cover crops in conventional farming systems is encouraged as a method to control soil erosion and weeds, improve soil moisture and nutrient content, and reduce soil compaction and losses of nitrogen (N) to the environment (AHDB, no date). Incorporating cover crops into rotations has rapidly increased in recent years (Storr et al., 2019) due to an increase in the uptake of 'regenerative' or 'sustainable' farming practices, and the inclusion of cover crops in the UK Government's Sustainable Farming Incentive (SFI) scheme (e.g., actions SAM2/CSAM2, SOH2, SOH3) (Defra, 2025a), and many water company schemes. Twenty-seven percent of farms (amounting to c.40 % of the agricultural area) surveyed in the 2023 British Survey of Fertiliser Practice (BSFP) indicated that they grow cover crops as part of regenerative practices (Defra, 2024a).

The benefits of cover crops are well established, however their legacy effect on subsequent crops in the rotation (i.e., the immediately following cash crop and second following crop) is more uncertain, in particular, the amount and timing of the nutrients released from cover crops and the availability of these to the following cash crop(s). Guidance within The AHDB Nutrient Management Guide (RB209), for example, is vague in relation to the effect of cover cropping on soil N supply (SNS), stating that a well-established cover crop destroyed by the end of February "can release useful quantities of nitrogen for the following spring crop; sufficient to increase the SNS by up to two Indices", whereas for cover crops destroyed later in the spring "the amount and timing of nitrogen release is difficult to predict" (AHDB, 2023a). An increase in SNS by up to two Indices (e.g., from Index 0/1 to 2/3) would equate to a reduction in N fertiliser requirement for spring barley of between 50-80 kg N/ha, whereas the reduction for sugar beet would be only 20-40 kg N/ha. Moreover, there is no guidance on the potential release of other nutrients, such as phosphorus (P) and potassium (K), from cover crop residues, with P supply from cover crops often related to the inclusion of buckwheat in species mixes (Hallama et al., 2018), and is poorly researched in relation to cover cropping more widely (Liu et al., 2019).

With more farmers integrating cover cropping into arable rotations, there is a clear need for an improved understanding of nutrient release from cover crops into the soil and ultimately the amount and timing of nutrient availability to the subsequent cash crop(s). When integrated into nutrient management plans, this information will help farmers to better manage their nutrient inputs for maximum efficiency.

The evidence gathered by this quick scoping review (QSR) will provide an understanding of the scope and volume of existing evidence on nutrient release from cover crop residues, and will consider the methodologies used to predict nutrient release from cover crop residues and the existing tools available to farmers to estimate biomass return from cover crops.

2.1. Objectives

The overall aim of this project is to collate and review all existing evidence to inform the feasibility of creating a Decision Support Tool (DST) to help UK farmers predict nutrient release following the use of cover crops and provide recommendations for future development of the tool. This report covers Task 1 of the project.

3. Materials and methods

3.1. Primary research questions

The QSR includes 5 primary Research Questions which were developed by the project team based on the project objectives and agreed with the steering group. The primary questions were 'impact' questions which aimed to identify the current literature available on the amount of cover crop residues returned to soil and their nutrient content and timing of return, the amount and timing of nutrients available to the following cash crop, the methodologies currently used to predict the timing and amount of nutrients released from cover crop and the data they require, and the tools available to farmers to estimate the amount of over crop biomass returned to the soil.

The primary research questions were:

1. What evidence is available on the amount (e.g., quantity of biomass and nutrients), nutrient content and quality (e.g., carbon:nitrogen (C:N) ratio) of aboveground and belowground (e.g.,roots/leguminous nodules) residue returned to the soil from cover crops (e.g., summer, winter, single and multispecies cover crops) grown in temperate climates?
2. What evidence is available on the amounts and timing of nutrients (e.g., N, P and K) released from cover crops (e.g., summer, winter, single and multispecies cover crops) grown in temperate climates?
3. What evidence is available on the timing and amount of nutrients available to the following cash crop(s) (different types of cash crops will be compared (e.g., early versus late sown spring crops))?
4. What are the methodologies (e.g., direct measurements of cover crop N residues, soil mineral N (SMN), additionally available N (AAN), potentially mineralisable N (PMN), crop sensors or modelling approaches) used to predict the timing and amount of nutrients released from cover crops grown in temperate climates and what data is required to predict this?
5. What are the tools (e.g., in field crop sensors or mobile apps (e.g., Canopeo) to calculate normalized difference vegetation index (NDVI) or percentage aboveground cover) available to farmers to estimate the amount of cover crop biomass being returned to the soil, and is evidence available evaluating the robustness of such tools?

3.2. Quick scoping review process

The QSR process began by developing search criteria which could be used to identify relevant literature (Table 1 and Table 2). Boolean operators were used (Table 3) to generate search terms (Table 4). The QSR was carried out following the PRISMA protocol. The key steps of the PRISMA protocol are as follows:

3.2.1. Conduct systematic searches

Systematic searches were conducted using the search terms outlined in Section 2.4 (Table 4). For each search engine, the following information was documented for each search: date of the search, total number of hits, and first 50 titles (and authors). The use of the first 50 titles provided sufficient resources to critically appraise the evidence in the detail required to fulfil the project aims within the timeframe of the project.

3.2.2. Evidence screening 1: Title screening using RAG (Reviewer 1)

Red-Amber-Green (RAG) rankings were used to screen the evidence based on the title, where Green is ‘clearly relevant’, Amber is ‘uncertain’, and Red is ‘clearly not relevant’. Evidence marked as Red was discarded. Evidence marked as Green or Amber was carried through to the abstract screening stage.

To avoid the duplication of work, at this stage duplicate titles was removed.

3.2.3. Evidence screening 2: Abstract screening using RAG (Reviewer 1)

Working first through Green and then Amber titles, the abstract, executive summary, or introduction and concluding paragraphs (dependent on availability) of each piece of evidence was evaluated using RAG rankings. Evidence marked as Red was discarded. Evidence marked as Green or Amber was carried through to the full reading stage.

At this stage, 10 % of the abstracts were screened by a second reviewer for quality control purposes.

3.2.4. Evidence screening 3: Full reading

Working first through the Green and then Amber abstracts, the full piece of evidence was read and evaluated using RAG rankings. Evidence marked as Red was discarded. Evidence marked as Green was carried through to the data extraction stage.

3.2.5. Complete data extraction

The resultant pieces of evidence marked as Green (clearly relevant) were extracted.

3.3. Search criteria

The systematic searches (Table 4) were conducted in Web of Science and Google Scholar to obtain peer-reviewed published literature. In addition to the peer-reviewed literature, other (grey) literature were collated from previous and ongoing projects. These included the Nitrogen Release from Cover Crops project for Affinity Water and Portsmouth Water (NiCCs), the Nitrate Leaching Tool Crop Research project for Environment Agency, the Rapid Assessment of Crop Residue

Nitrogen Release project for Wessex Water, the ongoing AHDB cover crop destruction review, and any other available evidence from the Cover Crop Guide (https://covercropsguide.co.uk/). Relevant data from these projects were incorporated into the QSR to enhance the evidence base.

Table 1 and Table 2 detail the inclusion and exclusion criteria relevant to all Research Questions for the QSR. These criteria were applied by researchers from evidence screening stage 2 onwards (abstract screening using RAG).

Table 1: Inclusion criteria

Inclusion criteria	Rationale
Research conducted in temperate climates (i.e., UK, Ireland, France, Belgium, Netherlands, Denmark, Germany, Luxembourg, Austria, Czechia, New Zealand, Northern Spain, Poland)	The project is focused on nutrient release from cover crops grown in temperate climates, so evidence from countries with these climate conditions was included
Peer-reviewed and non-peer-reviewed (grey) literature	To ensure the most relevant research relating to nutrient release from cover crops is included, peer-reviewed and non-peer-reviewed (grey) literature was included
Research focused on the timing and amount of nutrients released from cover crops and methodologies used to estimate/predict this	The project was focused on the timing and amount of nutrients released from cover crops and methodologies used to estimate/predict this

Table 2: Exclusion criteria

Inclusion criteria	Rationale
Research not written in English	The research team were all English speakers
Academic research in the format of books or theses	The time frame in which the QSR can be conducted did not allow for peer-reviewed evidence larger than academic journal articles
Research not focused on nutrient release from cover crops and/or methodologies used to estimate/predict this	The project was focused on nutrient release from cover crops and the methodologies used to estimate/predict this so research outside of this scope was excluded
Published before 2010	The most relevant evidence to research today (i.e., that published in the last 15 years) was

	included

3.4. Search terms

Boolean search terms were used during search term generation and when conducting systematic searches. Boolean search terms use the operator 'AND' to ensure multiple key words/phrases are included in the search results, and 'OR' to broaden the search to ensure one of the specified key words/phrases are included in the search results (Table 3).

Table 3: Explanation and examples of Boolean search terms

Operator	Example	Result
AND	"Cover crop*" AND "Residue*"	Identify literature with both "Cover crop*" and "Residue*"
OR	"Nitrogen" OR "Soil mineral nitrogen" OR "Additionally available nitrogen" OR "Potentially mineralisable nitrogen"	Identify literature with either "Nitrogen" or "Soil mineral nitrogen" or "Additionally available nitrogen" or "Potentially mineralisable nitrogen"
" "	"Soil mineral nitrogen"	Identify literature with the exact phrase "Soil mineral nitrogen"
( )	"Cover crop*" AND "Residue*" AND ("Nitrogen" OR "Phosphorus" OR "Potassium")	Identify literature with "Cover crop*" and "Residue*" and "Nitrogen" or "Phosphorus" or "Potassium"
*	"Cover crop*"	Identify literature with "Cover crop", "Cover crops", "Cover cropping"

Each search was structured to ensure that all key words/phrases were relevant to the Research Question of interest were included. The search strings used for each question are detailed in Table 4.

Table 4: Search strings used to identify evidence.

Research question	Search string
1	("Cover crop*" OR "Catch crop*" OR "Green manure*") AND "Residue*" AND ("Summer" OR "Winter" OR "Multispecies") AND ("Biomass" OR "Dry matter" OR "Above ground" OR "Aboveground") AND ("Nutrient release" OR "Nitrogen" OR "Phos*" OR "Potas*" OR "CN ratio" OR "C:N ratio" OR "C:N" or "Temperature") AND ("UK" OR "Ireland" OR "France" OR "Belgium" OR "Netherlands" OR "Denmark" OR

	“Germany” OR “Luxembourg” OR “Austria” OR “Czechia” OR “New Zealand” OR “Northern Spain” OR “Poland” OR “temperate”)
	(“Cover crop*” OR “Catch crop*” OR “Green manure*”) AND “Residue*” AND (“Summer” OR “Winter” OR “Multispecies”) AND (“Biomass” OR “Dry matter” OR “Below ground” OR “Belowground” OR “Root*” OR “Nodule*”) AND (“Nutrient release” OR “Nitrogen” OR “Phos*” OR “Potas*” OR “CN ratio” OR “C:N ratio” OR “C:N” or “Temperature”) AND (“UK” OR “Ireland” OR “France” OR “Belgium” OR “Netherlands” OR “Denmark” OR “Germany” OR “Luxembourg” OR “Austria” OR “Czechia” OR “New Zealand” OR “Northern Spain” OR “Poland” OR “temperate”)
2	(“Cover crop*” OR “Catch crop*” OR “Green manure*”) AND (“Summer” OR “Winter” OR “Multispecies”) AND ((“Nutrient release” OR “Nutrient supply”) OR (“Nitrogen release” OR “Nitrogen supply”) OR (“Phosp* release” OR “Phosp* supply”) OR (“Potas* release” OR “Potas* supply”)) AND (“UK” OR “Ireland” OR “France” OR “Belgium” OR “Netherlands” OR “Denmark” OR “Germany” OR “Luxembourg” OR “Austria” OR “Czechia” OR “New Zealand” OR “Northern Spain” OR “Poland” OR “temperate”)
3	(“Cover crop*” OR “Catch crop*” OR “Green manure*”) AND “Available” AND ((“Nutrient release” OR “Nutrient supply”) OR (“Nitrogen release” OR “Nitrogen supply”) OR (“Phosp* release” OR “Phosp* supply”) OR (“Potas* release” OR “Potas* supply”) OR (“Replacement value” OR “Fertili*er replacement value”)) AND (“Crop*” OR “Following crop*” OR “Following” OR “Subsequent crop*” OR “Subsequent”) AND (“UK” OR “Ireland” OR “France” OR “Belgium” OR “Netherlands” OR “Denmark” OR “Germany” OR “Luxembourg” OR “Austria” OR “Czechia” OR “New Zealand” OR “Northern Spain” OR “Poland” OR “temperate”)
4	(“Cover crop*” OR “Catch crop*” OR “Green manure*”) AND ((“Nutrient release” OR “Nutrient supply”) OR (“Nitrogen release” OR “Nitrogen supply”) OR (“Phosp* release” OR “Phosp* supply”) OR (“Potas* release” OR “Potas* supply”) OR (“Replacement value” OR “Fertili*er replacement value”)) AND (“Predict*” OR “Estimat*”) AND (“UK” OR “Ireland” OR “France” OR “Belgium” OR “Netherlands” OR “Denmark” OR “Germany” OR “Luxembourg” OR “Austria” OR “Czechia” OR “New Zealand” OR “Northern Spain” OR “Poland” OR “temperate”)
	(“Cover crop*” OR “Catch crop*” OR “Green manure*”) AND ((“Nutrient release” OR “Nutrient supply”) OR (“Nitrogen release” OR “Nitrogen supply”) OR (“Phosp* release” OR “Phosp* supply”) OR (“Potas* release” OR “Potas* supply”) OR (“Replacement value” OR “Fertili*er replacement value”)) AND ((“Residue” AND “Nitrogen”) OR “Soil mineral nitrogen” OR “Additionally available nitrogen” OR “Potentially mineralisable nitrogen” OR “Sens*” OR “Model*” OR “Index”) AND (“UK” OR “Ireland” OR “France” OR “Belgium” OR “Netherlands” OR “Denmark” OR

	“Germany” OR “Luxembourg” OR “Austria” OR “Czechia” OR “New Zealand” OR “Northern Spain” OR “Poland” OR “temperate”)
5	(“Cover crop*” OR “Catch crop*” OR “Green manure*”) AND (“Estimat*” OR “Predict*”) AND “Biomass return*” AND (“Sens*” OR “Model*” OR “Index” OR “App*”)

When using Web of Science, researchers ensured that only the ‘Web of Science Core Collection’ database was used, and that the ‘All topics’ option was selected next to the search bar, to ensure the most relevant evidence was identified. When using Google Scholar, ‘Include citations’ was unticked to ensure that only literature was identified rather than citations of literature.

It should be noted that the use of Boolean operators differs by search engine. For example, Web of Science requires all key words and phrases to be within “ ”, whereas Google Scholar only requires phrases to be within “ ” and not single words. The use of parentheses is not required by Google Scholar.

3.5. Evidence screening

After the first 50 hits were downloaded for each search, the first phase screening ranked the publication title as ‘clearly relevant’, ‘clearly not relevant’ or ‘uncertain’ (Green, Red or Amber respectively). The second phase screening involved the ‘clearly relevant’ and ‘uncertain’ publications and involved reading the abstract or first paragraph of these publications. Evidence that was ‘clearly relevant’ or ‘uncertain’ was then read in full.

3.6. Data extraction

All evidence identified for complete data extraction was documented in the evidence extraction database.

For each publication the following information was captured:

- DOI and/or web link
- Title
- Author(s)
- Publication date
- Evidence format (i.e., journal paper)
- Referencing details (i.e., journal, volume, issue, page numbers)
- Abstract, executive summary, or introduction and concluding paragraphs (dependent on availability)
- Availability of relevant evidence related to the research questions, including but not limited to:
    - Study site information (i.e., country, climate, soil)
    - Cover crop type

- Cover crop destruction method
- Amount of above and/or below ground biomass
- Whether study contains information on residue quality (i.e., C:N ratio, water soluble carbohydrate) – this was to be marked as Yes or No
- Amount of N, P and/or K released
- Amount of N, P and/or K taken up by following crop
- Timing of N, P and/or K released
- Methodology used to predict timing/amount of N, P and/or K release

3.7. Secondary research questions

From the findings of the review it was anticipated that the following secondary Research Question would emerge:
1. What is the suitability of decision support methodologies for other potential soil nutrient building options aside from cover crops (including companion crops, undersown maize, (legume) fallows and herbal leys)?

3.8. Systematic mapping approach

Following the collation of the relevant peer-reviewed and grey literature and extraction of data into the database, a systematic mapping approach was used to evaluate the data. As specified by the exclusion criteria, the systematic map covers only data collected in temperate climates, so as to be relevant to the context of the UK and the potential development of a DST for predicting nutrient release from cover crops in the UK. The systematic map consists of a report describing the QSR process, a database of the extracted data from relevant studies, and bar charts and heat maps showing the scope of the data of relevance to each Research Question.

4. Results

4.1. Number and type of studies

4.1.1. Peer-reviewed literature

In total, 14 separate searches were carried out resulting in a total of 53,131 peer-reviewed articles. A total of 615 papers were screened. Following screening of the paper titles and the removal of papers subsequently classified as Red and papers which were duplicates, 215 papers were remaining. Following the screening of the abstracts of these papers and removal of any papers subsequently marked as Red, 135 papers were left for full-text screening. Following full-text screening, data from 45 papers were included in the analysis, many of which contained information relevant to multiple Research Questions (Table 5), equating to 436 individual measurements.

Table 5: Summary of peer-reviewed literature relevant to each Research Question. Note some

papers were relevant to multiple questions.

Research question	No. papers
1: Amount, nutrient content and quality of cover crop residue returned to soil	38
2: Amount and timing of nutrients released from cover crop residue	26
3: Amount and timing of nutrients available to following cash crop(s)	15
4: Methods used to predict amount and timing of nutrients released from cover crop residues	5
5: Tools available to farmers to estimate amount of cover crop biomass returned to soil	3

4.1.2. Grey literature

Grey literature relevant to the QSR was provided by ADAS and experts with knowledge of existing reports/grey literature relevant to the project. A total of 38 pieces of grey literature were screened and 13 marked as Green for inclusion in the analysis, some of which were relevant to multiple Research Questions (Table 6), equating to 113 individual measurements.

Table 6: Summary of grey literature relevant to each Research Question. Note some pieces of grey literature were relevant to multiple questions.

Research question	No. papers
1: Amount, nutrient content and quality of cover crop residue returned to soil	6
2: Amount and timing of nutrients released from cover crop residue	5
3: Amount and timing of nutrients available to following cash crop(s)	2
4: Methods used to predict amount and timing of nutrients released from cover crop residues	0
5: Tools available to farmers to estimate amount of cover crop biomass returned to soil	6

4.2. Overview of the literature

A total of 51 studies (peer-reviewed and grey literature) were relevant for inclusion in the QSR, with 12 of these being studies conducted in the UK. This equated to 549 individual measurements, with many of these measurements relevant to multiple Research Questions; 453 individual measurements were from field experiments (38 studies), 58 individual measurements from laboratory experiments (8 studies), and 20 individual measurements from 1 study which included both field and laboratory experiments. The majority of measurements were taken at sites in the UK (n=165 individual measurements), with sites in Germany being the next most frequent (n=130 individual measurements) (Figure 1). More measurements were taken from sites with a sandy loam soil (n=124 individual measurements) than any other soil texture (Figure 2). Measurements taken in the UK were mainly from sites with clay loam or sandy clay loam soils (Figure 2).

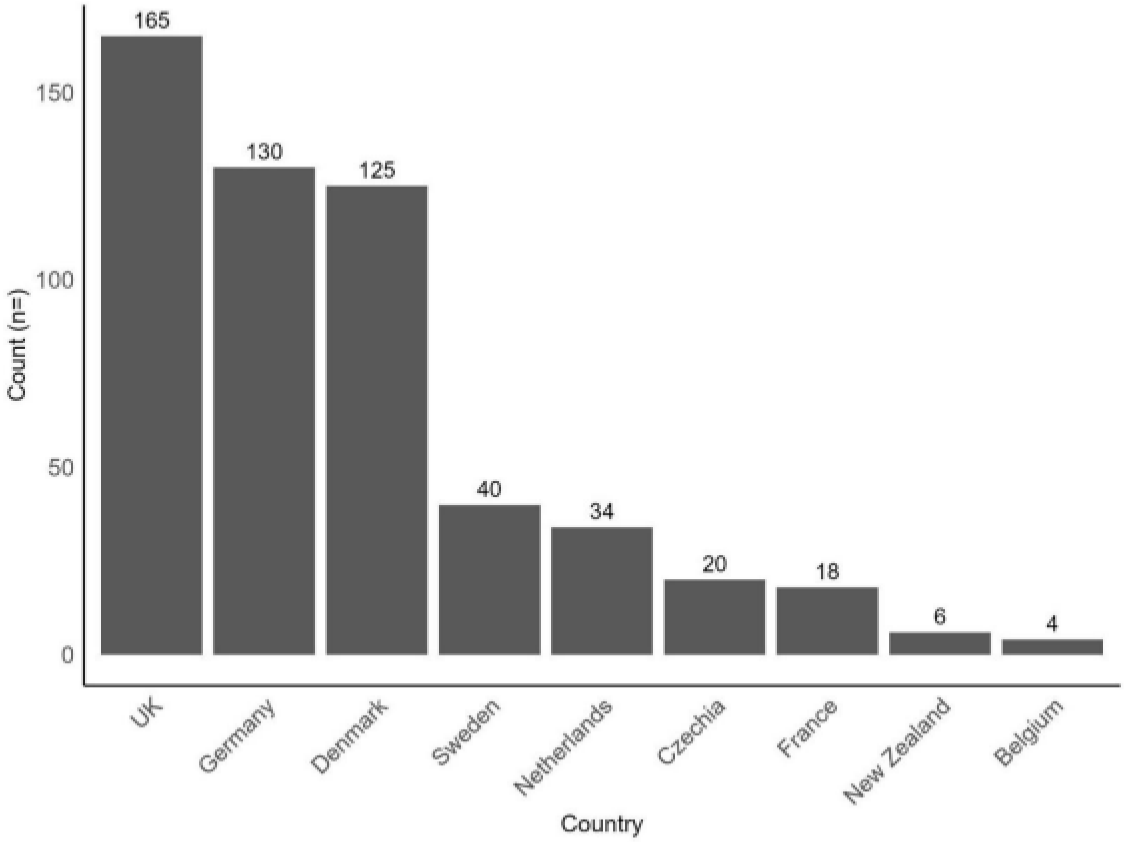

Figure 1: Number of individual measurements per country within the collated dataset. Note that n does not equal 549 as some data (e.g., that related to Question 5 - tools used by farmers) did not have a single country associated with it.

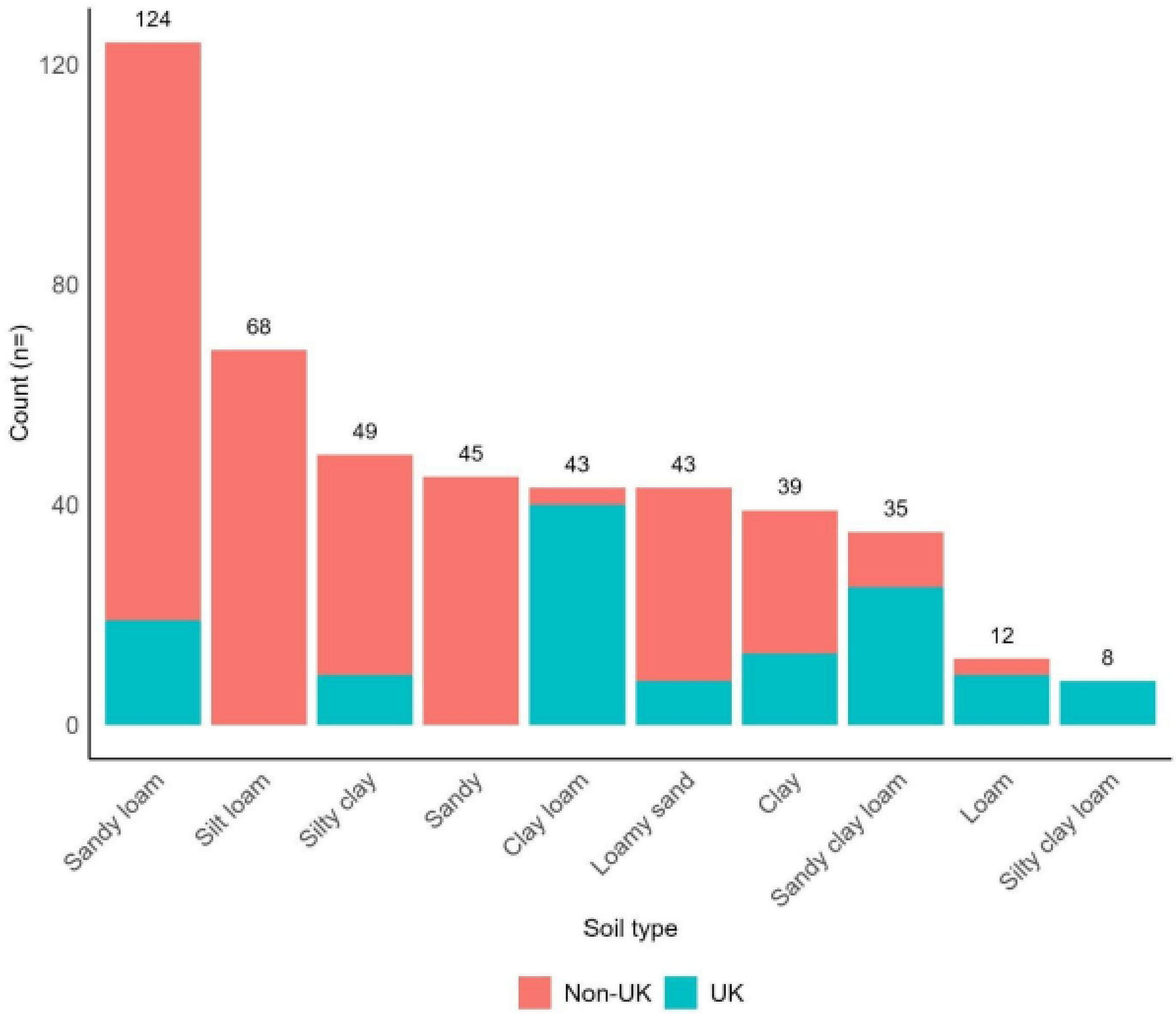

Figure 2: Number of individual measurements by soil texture within the collated dataset, split by UK and non-UK measurements. Note that n=466 as some studies did not report soil texture, and for some evidence (e.g., that related to Question 5 - tools used by farmers) it was not necessary to collect soil texture information.

Single species cover crops were studied more than multispecies cover crops, and winter cover crops were studied more than summer and autumn cover crops (Figure 3). Summer cover crops are here defined as those sown in late spring/early summer and terminated prior to the sowing of a winter crop. Winter cover crops include those sown late summer/early autumn and destroyed in spring before the planting of a spring crop. Autumn cover crops, commonly known as catch crops, include those sown in July/August and destroyed in October/November, and were typically grown at sites in Denmark, Czechia and Sweden. More detail on the management of the autumn cover crops in the dataset is included in Table 15 (Appendix 1). Measurements made in the UK were from winter cover crops only (Figure 3), with no measurements of summer or autumn cover crops.

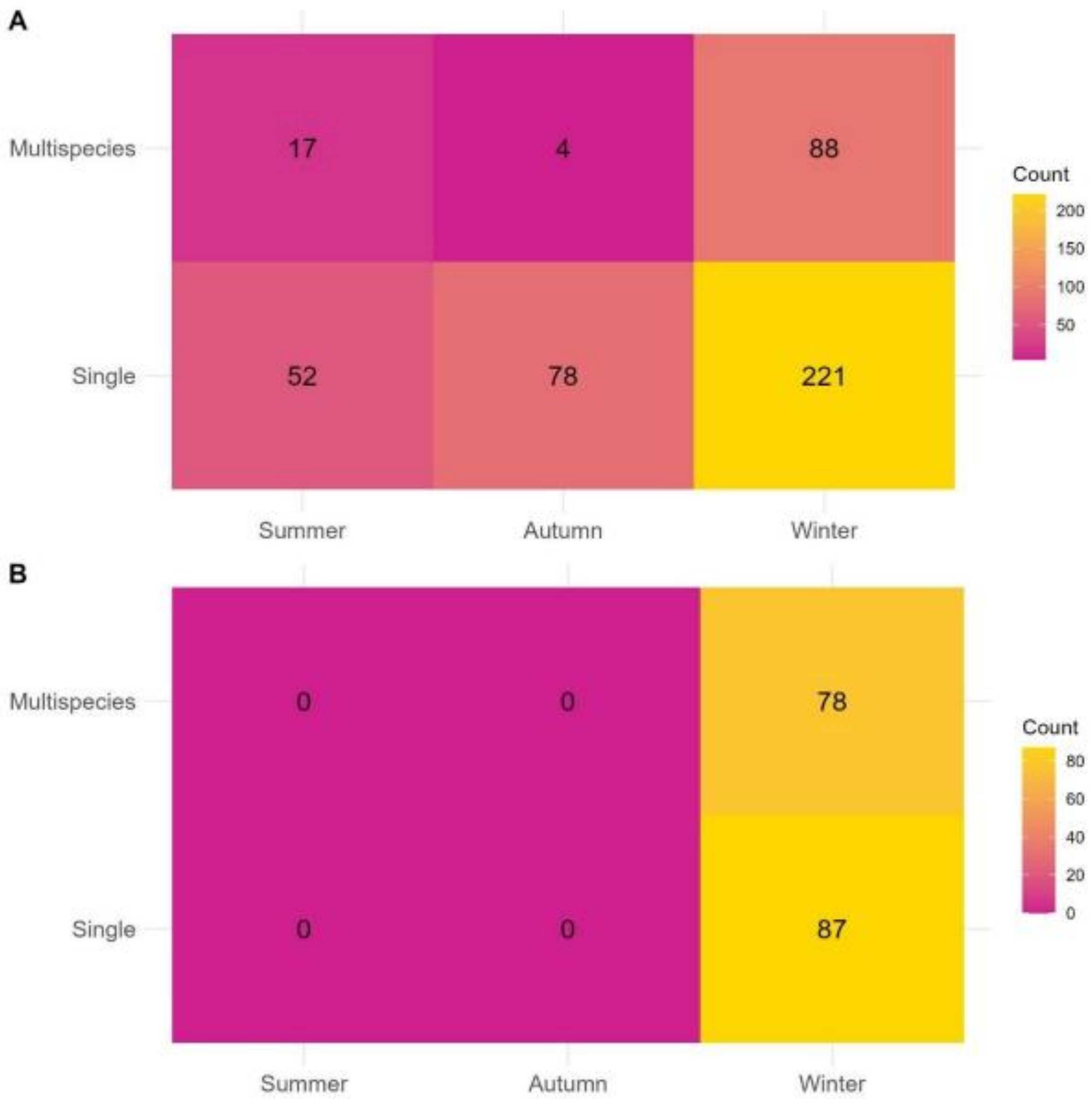

Figure 3: Distribution of cover crop types within the collated dataset (A) and for UK data only (B). Note that n does not equal 549 as some data (e.g., that related to Question 5 -tools used by farmers) did not have a cover crop associated with it and some studies did not report the time of year the cover crop was planted (e.g., if a laboratory experiment).

Across the entire dataset, the most frequently studied cover crop group were brassicas, with 116 individual measurements (from 30 studies), followed by legumes, with 89 individual measurements (from 30 studies) and mixes containing legumes, with 86 individual measurements (from 20 studies) (Figure 4). Non-legume mixes and legume mixes were the most popular cover crop types of the UK measurements (Figure 4). More details on the specific species of cover crops in the dataset and their relevance to each Research Question are included in Table 15 and Table 16 (Appendix 1).

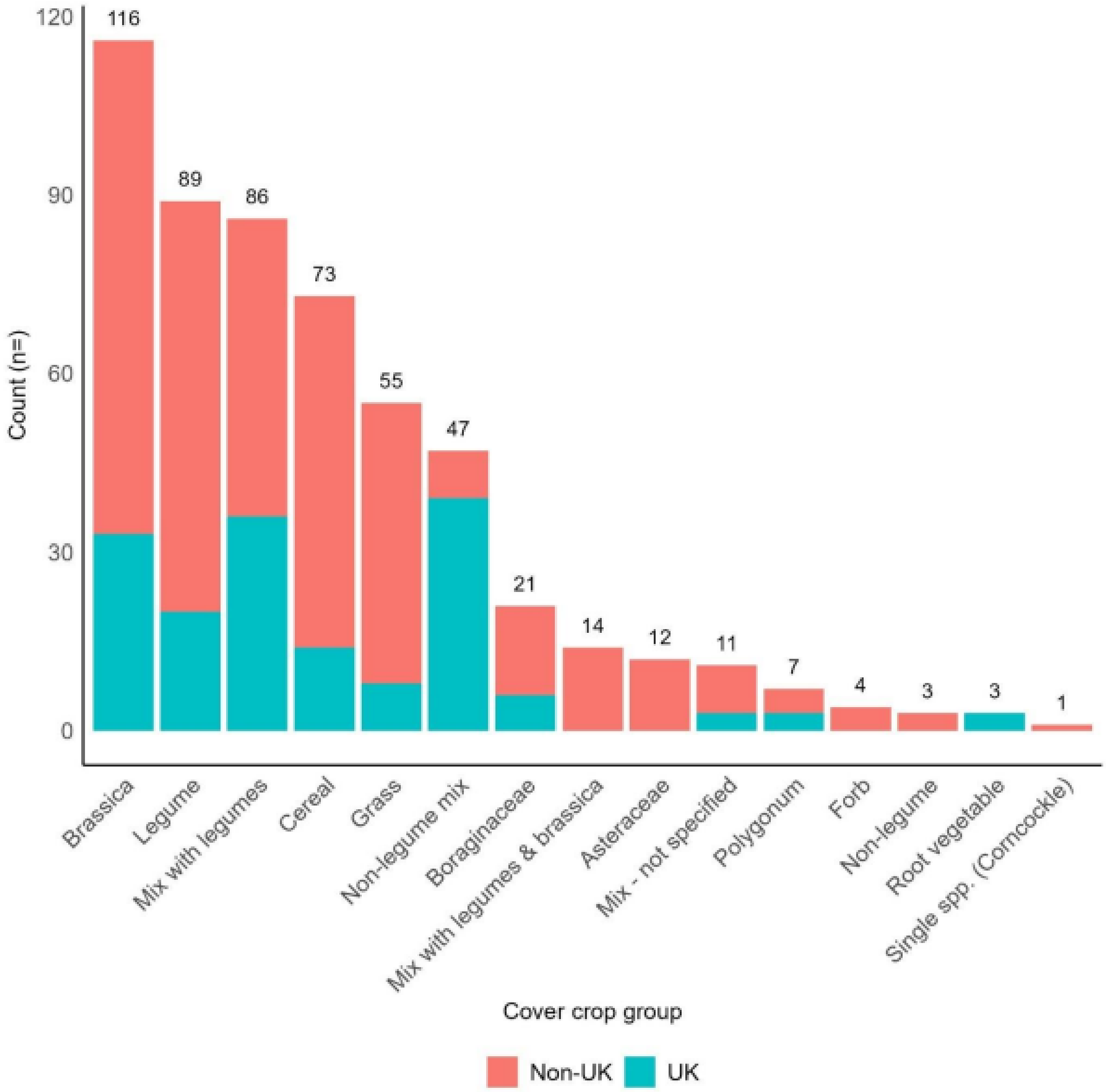

Figure 4: Number of individual measurements by crop type group within the collated dataset split by UK and non-UK measurements. Note that n does not equal 549 as some data (e.g., that related to Question 5 - tools used by farmers) did not have a cover crop (group) associated with it. Note Boraginaceae includes Fiddleneck and Phacelia, Asteraceae includes Chicory and Safflower, Polygonum includes Buckwheat and Sorrel, and Single spp. refers to Corncockle (a Caryophyllaceae).

4.3. Evidence available on the amount, nutrient content and quality of aboveground and belowground residue returned to the soil from cover crops grown in temperate climates (Research Question 1)

In total, 44 studies included data on the amount, nutrient content (i.e., amount of N, P or K in kg/ha) and/or quality (i.e., N % or C:N ratio) of cover crop residue returned to the soil, equating to 522 individual measurements. Sixteen of these studies reported data on both aboveground and belowground residues, 26 reported data on aboveground residues only and none reported data on belowground residues alone. Eleven of the 44 studies relevant to Research Question 1 included measurements which were taken in the UK, equating to 159 individual measurements. Table 7 provides an overview of the number of individual measurements of aboveground and belowground biomass quantity, nutrient content and quality across the dataset and specifically for UK-only measurements.

Table 7: Number of individual measurements of biomass quantity, nutrient content (N, P, K; kg/ha) and quality (C:N ratio, N%) for aboveground and belowground biomass. Number of studies that the data is collated from is reported in brackets. Measurements specifically from the UK are shown.

	Aboveground biomass		Belowground biomass	
	All data	UK only	All data	UK only
Biomass quantity	476 (41)	119 (9)	206 (16)	32 (3)
N amount	412 (37)	142 (9)	173 (13)	47 (2)
P amount	130 (11)	36 (3)	47 (3)	15 (1)
K amount	42 (5)	26 (2)	22 (2)	15 (1)
C:N ratio	234 (23)	53 (5)	89 (8)	0 (0)
N%	246 (26)	33 (3)	78 (8)	15 (1)

4.3.1. Aboveground biomass

Table 8: Number of measurements of aboveground biomass quantity, nutrient content (N, P, K; kg/ha) and quality (C:N ratio, N%) and combinations of these parameters. Number of studies that the data is collated from is reported in brackets. Measurements specifically from the UK are shown.

	All data	UK only
Biomass quantity only	27 (4)	15 (2)
Nutrient content only	38 (2)	38 (2)
Biomass quality only	0 (0)	0 (0)
Biomass quantity + nutrient content	107 (7)	53 (4)
Biomass quantity + quality	4 (4)	2 (1)
Nutrient content + biomass quality	8 (2)	2 (1)
Biomass quantity + nutrient content + biomass quality	299 (28)	49 (3)

The majority of studies reporting evidence on cover crop aboveground residue provided measurements of both biomass quantity and N content (Table 7). Table 8 shows the number of measurements on aboveground biomass quantity, nutrient content and quality. Typically, studies reported data on all 3 parameters (i.e., aboveground biomass quantity, nutrient content and biomass quality) and assessed these in combination.

In field experiments, the quantity of aboveground biomass was determined using quadrats or a measure of NDVI, and in laboratory experiments a known amount of aboveground biomass was added to pots. The nutrient content of the residues (e.g., N in kg/ha) was determined by multiplying the nutrient concentration of the residues (e.g., N%) by the amount of aboveground biomass.

4.3.2. Belowground biomass

Similar to the evidence on aboveground biomass, the data on belowground biomass residue was mainly focused on the residue quantity and N content (Table 7). Table 9 shows the number of measurements of belowground biomass quantity, nutrient content and biomass quality. Typically, the majority of studies reported data on all 3 parameters (i.e., belowground biomass quantity, nutrient content and biomass quality) and assessed these in combination. All measurements of belowground biomass were of cover crop roots, and there were no measurements of root nodules in isolation.

Table 9: Number of measurements of belowground biomass quantity, nutrient content (N, P, K; kg/ha) and quality (C:N ratio, N%) and combinations of these parameters. Number of studies that the data is collated from is reported in brackets. Measurements specifically from the UK are shown.

	All data	UK only
Biomass quantity only	67 (5)	17 (2)
Nutrient content only	34 (2)	32 (1)
Biomass quality only	0 (0)	0 (0)
Biomass quantity + nutrient content	0 (0)	0 (0)
Biomass quantity + quality	0 (0)	0 (0)
Nutrient content + biomass quality	0 (0)	0 (0)
Biomass quantity + nutrient content + biomass quality	139 (11)	15 (1)

The amount of belowground cover crop biomass was determined by destructive sampling (i.e., taking soil cores for root analysis or using a spade, or by comparing root material in a PVC pot with cover crops to a pot with no cover crops (as in Christensen et al., 2021)). Similarly to aboveground biomass, the nutrient content was determined by multiplying nutrient concentration by the amount of belowground biomass, or by calculating AAN from cover crop roots (as in Fontaine et al., 2020) – the latter measurement involved subtracting the N recovered from the soil pool from the total N uptake by the cover crop.

4.4. Evidence available on the amount and timing of nutrients released from cover crops grown in temperate climates (Research Question 2)

In total, 31 studies included data on the amount and/or timing of nutrients (i.e., N, P or K in kg/ha) released to the soil from cover crop residues, equating to 302 individual measurements. Sixteen studies measured both the amount and timing of nutrients released to the soil and 15 reported data on the amount released to the soil only. Table 10 provides an overview of the number of individual measurements of the amount and timing of nutrient release from cover crop residues to the soil.

The majority of studies reporting data on the amount of nutrient release to the soil focused on N, with fewer measurements of P and K (Table 10). Measurements from sites in the UK only reported the amount of N and P released from cover crop residues to the soil, with none reporting the amount of K released (Table 10). The timing of nutrient release to the soil was only considered by some studies that also measured the amount of N release from cover crop residues (n=175 individual measurements); no studies reported data on the timing of P or K release to the soil from cover crop residues (Table 10).

Table 10: Number of individual measurements of the amount and timing of nutrient release (N, P, K; kg/ha) from cover crop residues to the soil. Number of pieces of evidence that the data is collated from is reported in brackets. Measurements specifically from the UK are shown.

	Amount of nutrient release		Timing of nutrient release	
	All data	UK only	All data	UK only
N	292 (29)	71 (6)	175 (16)	14 (2)
P	41 (4)	31 (2)	0	0 (0)
K	9 (2)	0 (0)	0	0 (0)

Considering the distribution of N release measurements by cover crop type, the majority of these were for winter cover crops, primarily single species cover crops (n=152 individual measurements) followed by multispecies winter cover crops (n=49 individual measurements) (Figure 5). There were considerably fewer measurements of N release from summer and autumn cover crops (Figure 5). Measurements of nutrient release in the UK were from winter cover crops only (Figure 5). The amount and timing of N release from cover crop residues to the soil was mainly determined by measurements of SMN (i.e., both ammonium-N and nitrate-N) (n=254 individual measurements) or soil nitrate-N content alone (n=27 individual measurements). Twenty-one of the 22 studies measuring SMN accounted for background SMN (i.e., 'background' SMN from the same soil with and without a cover crop). Eighteen of the studies accounting for background SMN treated the control (i.e., non-cover crop) plots and cover crop plots the same (i.e., all with fertiliser or all without fertiliser), whereas the remaining 4 studies applied fertiliser to the cover crop treatments but not the control treatments. The amount of N release to the soil was determined by multiplying cover crop biomass quantity by the N% of the cover crop biomass, by incubating the residue-amended soil in a laboratory, or by measuring the total N content of the soil after residue addition. Measurements of P release from cover crops were limited to single species summer cover crops (n=3 individual measurements) and single species autumn cover crops (n=7 individual measurements), and K measurements were limited to multispecies summer cover crops (n=2 individual measurements) and single species autumn cover crops (n=7 individual measurements) (data not shown).

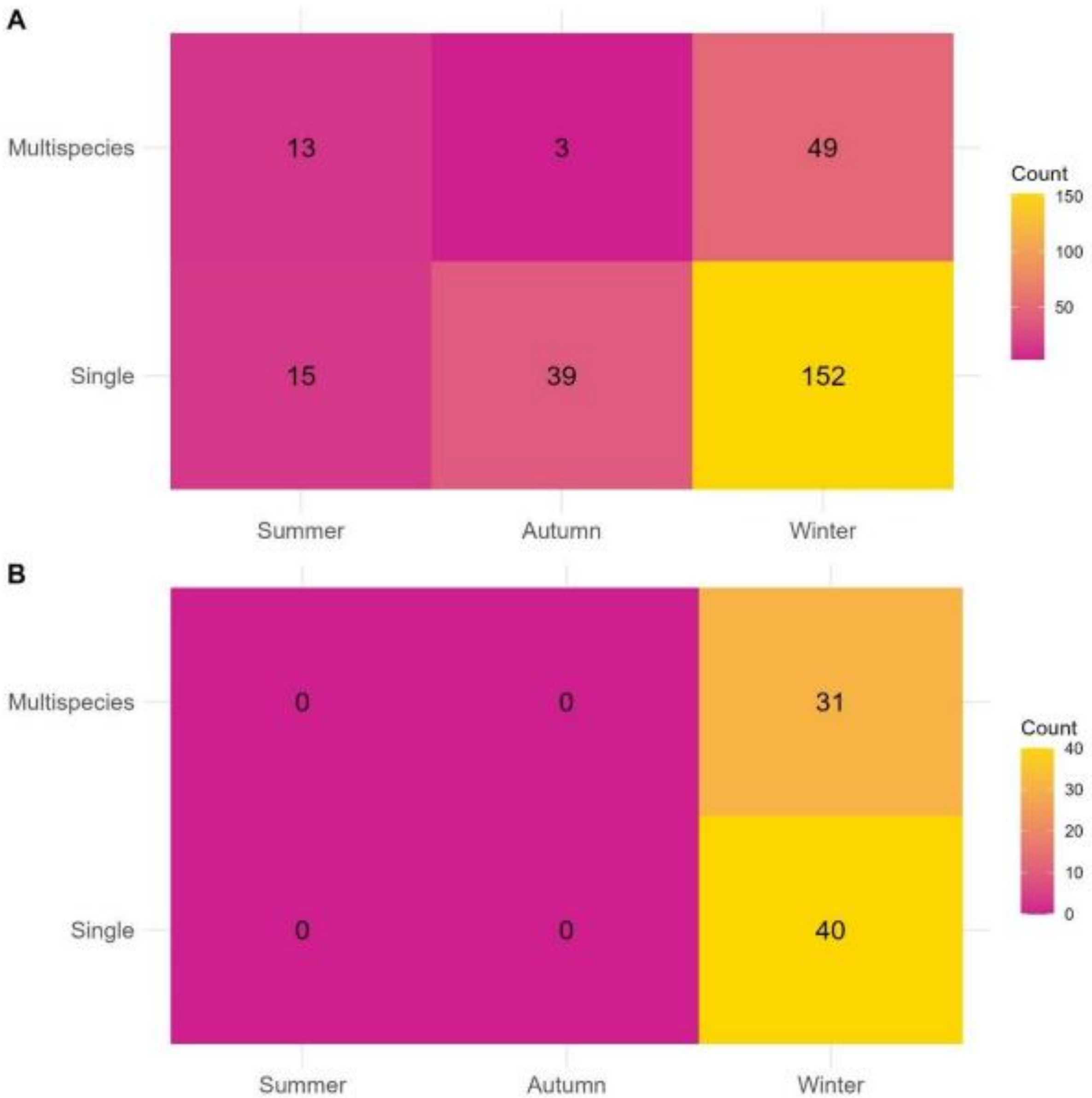

Figure 5: Distribution of measurements of N amount released from cover crop residues to the soil split by cover crop type across all countries (A) and for UK data only (B). Note data shown is only for studies that reported the amount of N release to the soil as these same studies also reported the timing of N release. Note that n does not equal 302 as some studies did not report the seasonality of the crop (i.e., those conducted in a laboratory).

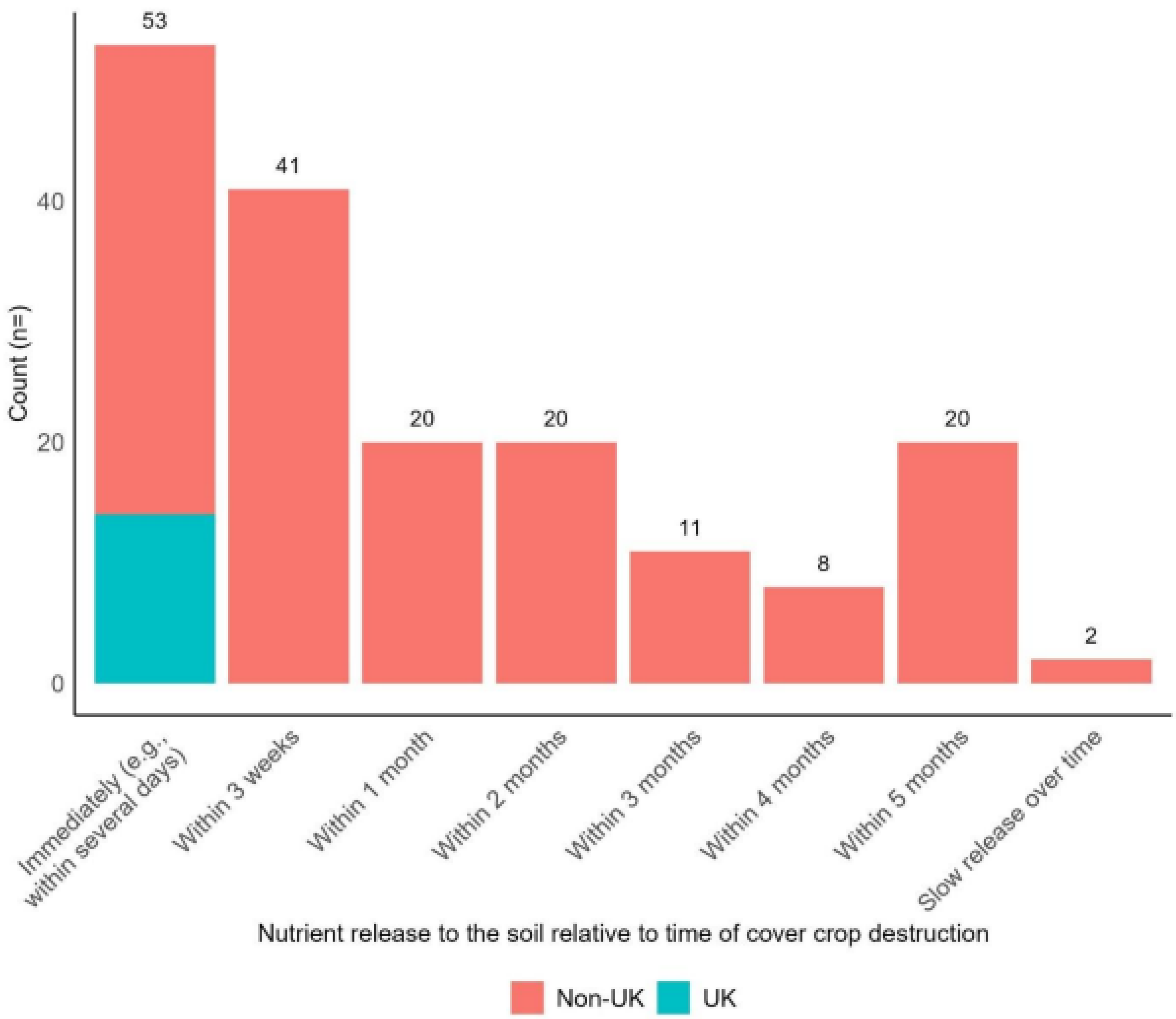

Figure 6: Number of individual measurements grouped by timing of nutrient (nitrogen) release to the soil relative to the date of cover crop destruction split by UK and non-UK measurements. Note that this is when the literature specified the majority of nutrient release occurs.

The timing of (the majority of) N release from cover crop residues to the soil ranged from immediately after the destruction of the cover crop to up to 5 months after the destruction of the cover crop (Figure 6). The category with the highest number of measurements was studies which reported the majority of N to be released from cover crop residues immediately (i.e., within a few days) after cover crop destruction (n=53 measurements, 30 % of the findings), with slightly fewer measurements in the category reporting that this occurred within 3 weeks of cover crop destruction (n=41 individual measurements). The number of individual measurements reporting the majority of N release to the soil to occur within 1, 2 or 5 months of cover crop destruction was identical (n=20 for each group), with fewer measurements reporting this to occur within 3 or 4 months of cover crop destruction (n=11 and n=8 individual measurements respectively). Most of the measurements were taken in non-UK countries, with measurements from sites in the UK finding that the majority of nutrient release to the soil occurred immediately - within several days of cover crop destruction (Figure 6). Existing research has suggested that the timing of nutrient release to the soil is related to the quality of the cover crop residues (i.e., C:N ratio, N%) (Adhikari et al., 2024; AHDB, 2025a), however exploring the relationship between these variables was outside the scope of the QSR.

4.5. Evidence available on the amount and timing of nutrients from cover crops grown in temperate climates available to the following cash crop (Research Question 3)

Research Question 3 focused on the availability of the nutrients released from cover crop residues to the following cash crop. Research Question 3 differs from Research Question 2, as it focuses on quantifying the amount of nutrients taken up by the cash crop (usually determined by fertiliser replacement value or crop N uptake), whereas Research Question 2 focuses on the amount and timing of nutrient release from cover crop residues to the soil (mainly based on the mineral N or nitrate-N content of the soil).

In total, 17 studies included data on the amount and/or timing of nutrients (i.e., N, P or K in kg/ha) released from cover crop residues available to the following cash crop, equating to 143 individual measurements. Very few of these measurements were from sites in the UK (n=22 individual measurements). Five studies measured both the amount and timing of nutrients available to the following cash crop and 12 studies reported data on the amount available to the following cash crop only. Table 11 provides an overview of the measurements of the amount and timing of nutrients (released from cover crop residues) available to the following cash crop.

Table 11: Number of individual measurements of the amount and timing of nutrient release (N, P, K; kg/ha) from cover crop residues available to the following cash crop. Number of pieces of evidence that the data is collated from is reported in brackets. Measurements specifically from the UK are shown.

	Amount of nutrients available to the following cash crop		Timing of nutrient availability to the following cash crop	
	All data	UK only	All data	UK only
N	143 (17)	22 (4)	63 (5)	0 (0)
P	3 (1)	0 (0)	0	0 (0)
K	0	0 (0)	0	0 (0)

The majority of measurements focused on N availability to the following cash crop (n=143 individual measurements), with far fewer measurements of P (n=3 individual measurements) and no measurements of K (Table 11). Measurements from sites in the UK only considered the amount of N available to the following cash crop, and did not include P or K availability. The timing of nutrient availability to the following cash crop was only considered by some of the papers which reported the amount of available N (n=63 individual measurements), and there were no measurements of the timing of P or K availability to the following cash crop (Table 11).

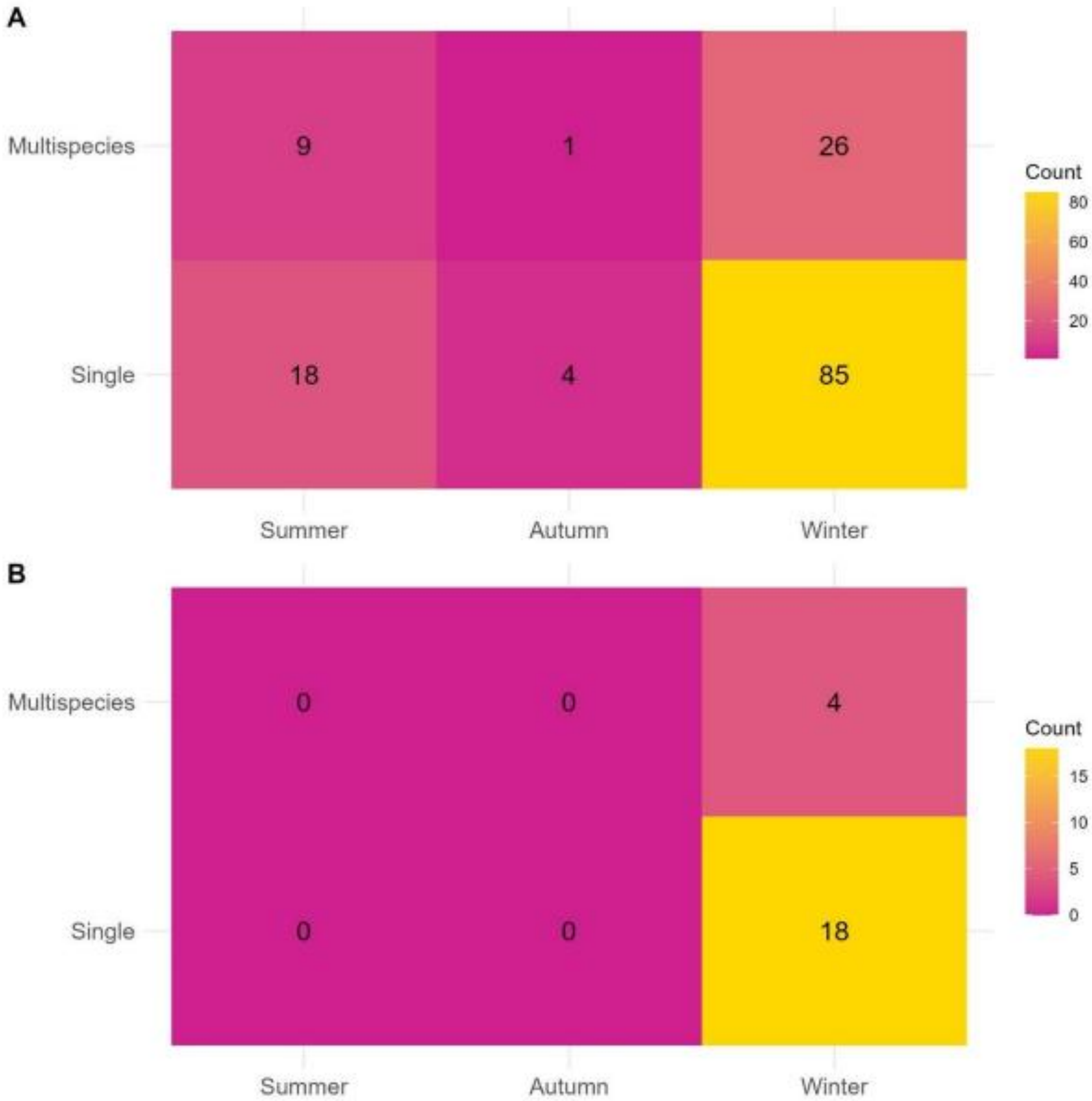

Figure 7: Distribution of measurements of the amount of N available from cover crop residues to the following cash crop split by cover crop type across all countries (A) and for UK data only (B). Note data is only shown for papers that reported the amount of N available to the following cash crop as these same papers also reported the timing of N availability.

Considering the distribution of nutrient availability measurements by cover crop type, most measurements of N availability were for winter cover crops, primarily single species cover crops (n=85 individual measurements) followed by multispecies winter cover crops (n=26 individual measurements) (Figure 7). There were considerably fewer measurements of N availability from summer and autumn cover crop residues to the following cash crop (Figure 7). Measurements made in the UK were for winter cover crops only (Figure 7), mainly single species winter cover crops, with no measurements from summer or autumn cover crops. The amount and timing of N from cover crop residues available to the following cash crop was most commonly determined by calculation of the fertiliser replacement value (n=76 individual measurements) and crop N uptake (n=48 individual measurements), with fewer measurements using excess atom fraction 15N in the laboratory or by determining the 'Neffect' (i.e., the difference in soil nitrate-N content between soils with and without cover crops, excluding N from other sources such as fertiliser; Thorup-Kristensen and Dresboll, 2010). Measurements of the amount of P available from cover crop residues were limited to single species summer cover crops (n=3 individual measurements) (data not shown).

The amount of N available to the following cash crop ranged between 0-120 kg N/ha, although the most common amount released ranged between 0-30 kg N/ha (n=80 individual measurements), followed by 31-60 kg N/ha (n=46 individual measurements) (Figure 8). The lowest amount of N available to the following cash crop was reported to be 0 kg N/ha (i.e., no effect of cover crop). For measurements made in the UK, the amount of N available to the following cash crop was never higher than 81 kg N/ha. The amount of P available to the following cash crop ranged between 0-20 kg P/ha (n=3 individual measurements) (data not shown). It is important to note that 16 of the 17 studies relevant to Research Question 3 included a control treatment with no fertiliser application (or a '0N control') and therefore accounted for 'background' SMN.

In terms of the amount of N available to the following cash crop, in studies that report a range between 0-30 kg N/ha, the most popular cover crop type was radish (n=16 individual measurements) (Figure 8A). For studies reporting that cover crops supply between 31-60 kg N/ha to the following cash crop, there was no dominant type of cover crop studied, with no more than 5 measurements per cover crop type, aside from rye (n=6 individual measurements). For studies reporting that cover crops supply >61 kg N/ha to the following cash crop, the overall number of observations were low (n=8 individual measurements). Overall, the most common cover crop amongst the UK data was radish (n=4 individual measurements), which supplied between 0-80 kg N/ha to the following cash crop (Figure 8B).

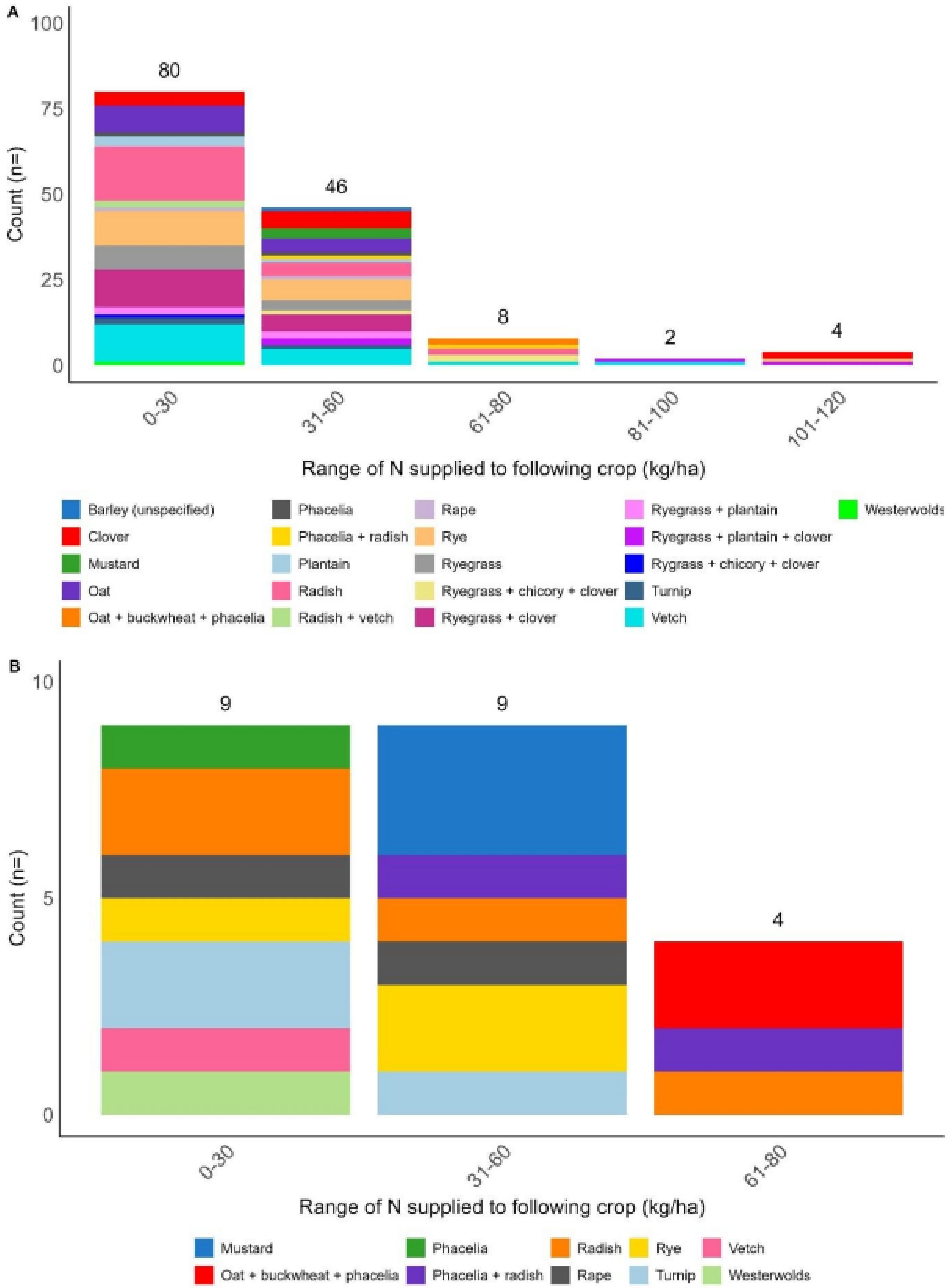

Figure 8: Number of individual measurements by range of N from cover crop residues supplied to the following cash crop grouped by cover crop residue type across all countries (A) and for UK data only (B). Note Rape includes Turnip Rape, Forage Rape and Oilseed Rape.

The distribution of measurements by type of immediately following cash crop (i.e., the first cash crop following the cover crop) is shown in Figure 9. Across all the data, spring barley was the most popular following cash crop (n=57 individual measurements), followed by sugar beet (n=32 individual measurements); 23 of the measurements reported did not specify the following cash crop type. For data from the UK, spring barley was the most popular following cash crop (n=12 individual measurements), followed by potato (n=8 individual measurements), with the remainder of the following cash crop types not being specified (Figure 10A and Figure 10B). One paper measured nutrient availability to the second following crop (Thorup-Kristensen and Dresboll, 2010), which was sown after barley, although the species of the second following crop was not specified. Spring barley and sugar beet were also the most popular following cash crops across all of the nutrient groups (n=31 and n=25 individual measurements, respectively) (Figure 10A); however, for sugar beet none of the data originated from the UK as BBRO were unable to contribute any data for this review.

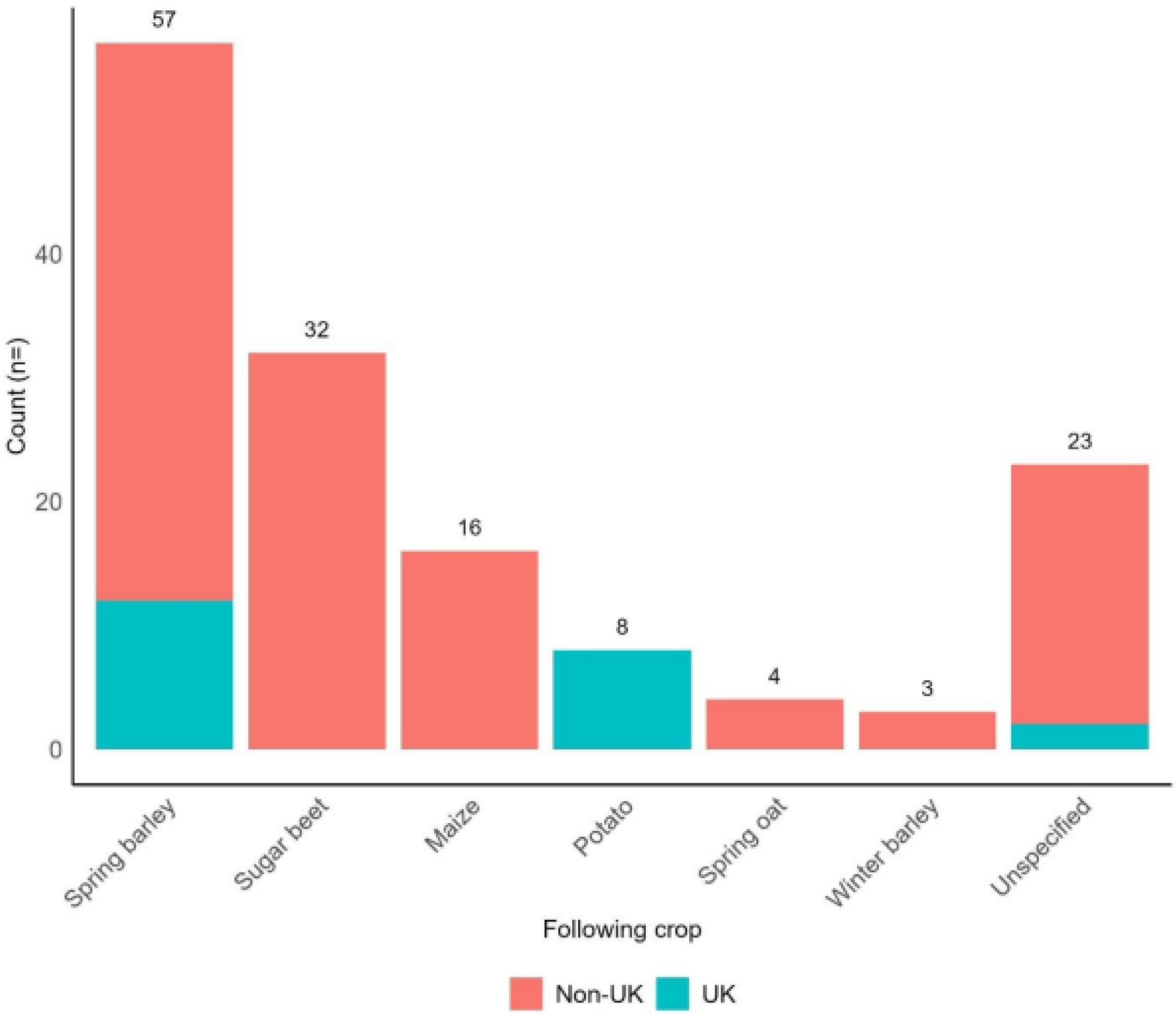

Figure 9: Number of individual measurements per following crop type for studies which measured cover crop N availability and the following crop type split by UK and non-UK measurements. Note that BBRO were unable to contribute any data for review, hence no data presented for sugar beet grown in the UK.

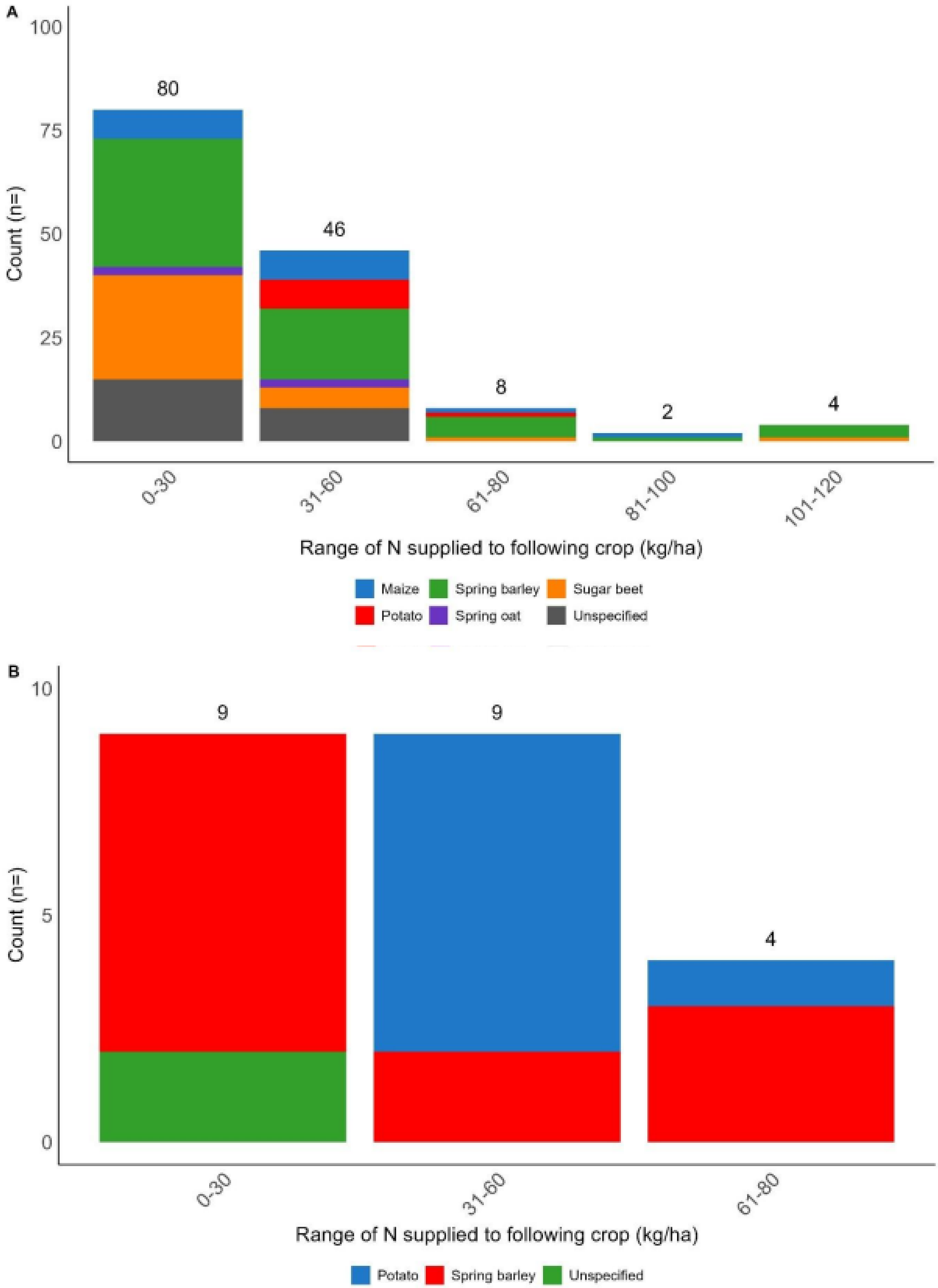

Figure 10: Number of individual measurements by range of N from cover crop residues supplied to the following cash crop grouped by the following crop type across all countries (A) and for UK data only (B).

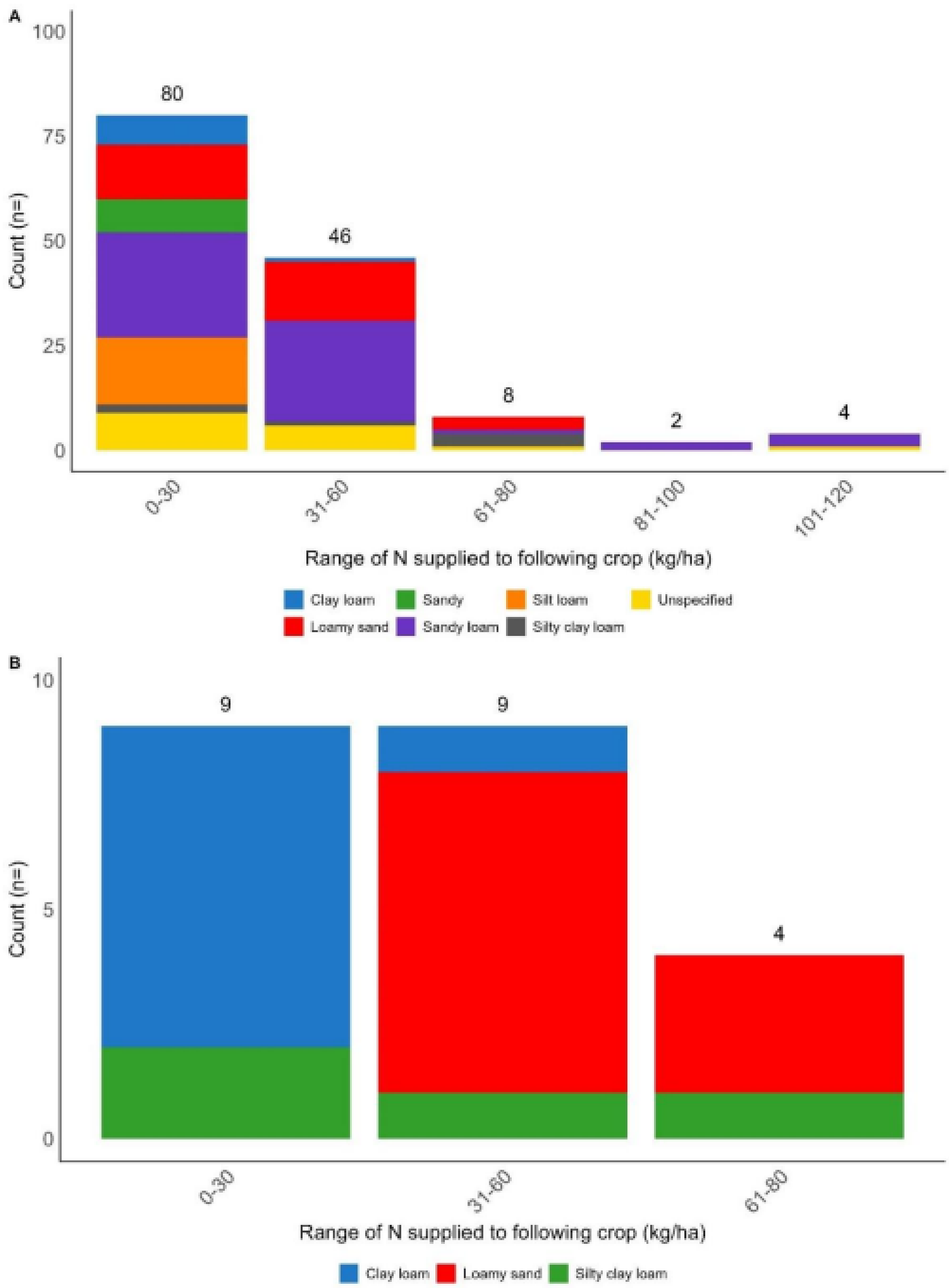

Figure 11: Number of individual measurements by range of N from cover crop residues supplied to the following cash crop grouped by soil type across all countries (A) and for UK data only (B).

When considering the amount of N from cover crop residues available to the following cash crop by soil type where 0-30 kg N/ha was available, this evidence was gathered from a wide range of soil types (Figure 11A). Sandy loam soils were present in every group, whereas clay loams, loamy sands and silty clay loams were only present in groups where the N return ranged between 0-80 kg N/ha. For the UK data (Figure 11B), the soil textures studied included clay loam, loamy sand and silty clay loam.

4.6. Overview of methodologies used to predict the amount and timing of nutrients released from cover crops grown in temperate climates and data requirements of these methodologies (Research Question 4)

4.6.1. Methods used by studies to determine the amount and timing of nutrient release from cover crop residues to the soil (Research Question 2)

A range of methods were used by the studies to determine the amount and timing of nutrients released from cover crop residues, including:

- **Total aboveground N uptake in the cover crop:** Determined by measuring both cover crop aboveground biomass and analysing cover crop residue for total N concentration (N%), in order to calculate total cover crop N uptake. De Notaris et al. (2025) state that this method can provide a direct measure of the amount of nutrients released from cover crop residues into the soil. However, as this method will not account for any losses of N or potential for N immobilisation, it is a better indicator of the maximum potential amount of N that can be released to the soil.
    - None of the UK studies relevant to Research Question 2 used this methodology.
- **Soil mineral N (SMN):** Soil mineral N, which is measured as nitrate-N plus ammonium-N, indicates the amount of readily available N in the soil, and so measurements of SMN before and after cover crop residue destruction/incorporation is a useful measure of the N released from the residues into the soil (AHDB, 2025a). Measuring this at time intervals following cover crop destruction/incorporation can provide an indication of when N is released (as in Kühling et al. (2023) and Thorman et al. (2024), for example). Soil mineral N is measured by extracting nitrate and ammonium from a soil sample, often with potassium chloride, and analysed using colorimetry.
    - All 6 of the UK studies relevant to Research Question 2 used this methodology.
- **Soil nitrate-N:** Measuring soil nitrate-N levels alone can provide an indication of the amount of N released from decomposing crop residues which is available for plant growth, as these residues contain organic N which is mineralised by soil microorganisms into plant-available nitrate (Tang et al., 2024). Soil nitrate-N concentration is measured via extraction in a laboratory.
    - None of the UK studies relevant to Research Question 2 used this methodology.
- **Soil total N:** Changes in soil total N can provide an indication of N released from crop residues, as returning crop residues to the soil provides an addition of organic matter, once residues decompose and organic N is mineralised (as in Verzeaux et al. (2016), for example).
    - None of the UK studies relevant to Research Question 2 used this methodology.

- **Laboratory incubation:** Incubating crop residues in a laboratory is a method used to simulate the decomposition process which would occur in the field. Environmental parameters, such as temperature and soil moisture, can be controlled. Measuring changes in SMN, for example, before, during, and after incubation, can show the amount of N released from crop residues and when (as in Suβ et al. (2024), for example).
    - None of the UK studies relevant to Research Question 2 used this methodology.

Additionally Available N refers to the N that will become available to the crop via mineralization throughout the growing season (AHDB, 2023b). Potentially Mineralisable N provides a measure of the fraction of organic soil N which can be converted to plant-available forms (USDA, 2014). Despite the expectation that these approaches would be used amongst the literature to predict nutrient release from cover crop residues (hence the reference to these methods in Research Question 4) none of the studies in this QSR used AAN or PMN to do this. In addition, sensors were not utilised as a method to predict nutrient release from cover crop residues; however they are relevant to Research Question 5 to determine the amount of cover crop biomass (Section 3.7).

4.6.2. Methods used by studies to determine the amount and timing of nutrients available to the following cash crop (Research Question 3)

A range of methods were used by the studies which determined the amount and timing of nutrients released from cover crop residues which were available to the following cash crop, including:

- **Fertiliser replacement value:** Fertiliser replacement value is a measure of the value of a product as a fertiliser, and the extent to which nutrients in organic amendments can replace those from a mineral fertiliser (Westerik et al., 2023). It provides an indication of the amount of mineral fertiliser that an organic material could replace whilst maintaining yield, thus indicating the amount of nutrients available to the following cash crop. The experimental design typically requires adjacent N fertiliser response plots, to allow the N recovered from the organic amendment (here cover crops) to be analysed compared to the manufactured N fertiliser yield response curve.
    - One of the 4 UK studies relevant to Research Question 3 used this methodology.
- **Nitrogen uptake of cash crop:** The N uptake of the cash crop can be used as an indicator of the availability of N in the soil, as it shows the amount of N that has been taken up by the cash crop (as in Cottney et al. (2020, for example).
    - Three of the 4 UK studies relevant to Research Question 3 used this methodology.
- **Apparent N recovery:** Apparent N recovery (or apparent recovery efficiency) refers to the difference in N accumulation of crops grown in plots receiving fertiliser compared to those in unfertilised plots (Karklins and Ruza, 2015). The net N recovered is equivalent to the amount of N supplied by the ’background’ soil including the previous cover crop.

Comparison of treatments with and without a cover crop will allow the contribution of cover crop N to be calculated.
    - None of the UK studies relevant to Research Question 3 used this methodology.
- **Excess atom fractionation of 15N:** Excess atom fractionation of 15N is a method used to track N cycling and fixation (He et al., 2009). The isotopic fractionation of N isotopes (i.e., 15N) occurs during N mineralisation and N fixation (Denk et al., 2017). The method provides a measure of the difference between the 15N isotope and the natural abundance of 15N, and so identifying areas where there is an excess of 15N (e.g., soil, plants) indicates where N is in abundance (as in Li et al. (2015), for example).
    - None of the UK studies relevant to Research Question 3 used this methodology.
- **'Neffect':** The 'Neffect' is a measure of the residual N supply from an organic amendment or previous crop that is potentially available to the following crop, determined as the difference in soil nitrate-N content between soils with and without cover crops (Thorup-Kristensen and Dresboll, 2010). This excludes N from other sources, such as fertiliser. It is influenced by the type of previous crop, application of organic amendments, and environmental factors such as soil type and climate conditions.
    - None of the UK studies relevant to Research Question 3 used this methodology.

4.6.3. Modelling approaches to predict amount and timing of nutrient release from cover crop residues to the soil

In total, 5 studies included modelling approaches to predict the amount and/or timing of nutrient release from cover crop residues to the soil, equating to 48 individual measurements, with none of this data from studies conducted in the UK. Two of the studies predicted both the amount and timing of nutrient release and 3 predicted the amount of nutrient release only. Table 12 provides an overview of the measurements of predicted nutrient release from cover crops.

Table 12: Number of individual measurements of predicted amount and timing of nutrient release (N, P, K; kg/ha) from cover crop residues to the soil. Number of pieces of evidence that the data is collated from is reported in brackets. Measurements specifically from the UK are shown.

	Predicted amount		Predicted timing	
	All data	UK only	All data	UK only
N	48 (5)	0 (0	9 (2)	0 (0)
P	0	0 (0)	0	0 (0)
K	0	0 (0)	0	0 (0)

The evidence predicting the amount/timing of nutrient release from cover crop residues only did so for N, with no predictions for P or K release (Table 12). More predictions were made of the amount of N released from cover crop residues, with fewer predictions of the timing of nutrient release. Considering the distribution of these predictions by crop type, more predictions were made for single species winter cover crops (n=23 individual measurements) and multispecies winter cover crops (n=11 individual measurements) than single species summer cover crops (n=4 individual measurements) and multispecies summer cover crops (n=4 individual measurements).

Three main methods were used amongst the literature to predict the amount of nutrient release from cover crop residues, these being the APSIM model, FASSET model and STICS model. The data requirements of these methodologies are detailed in Table 13. Only the APSIM model (or modified versions) was used to predict the timing of nutrient release from cover crop residues.

The APSIM model (or Agricultural Production Systems sIMulator) is a free crop modelling software which allows the simulation of a range of agricultural systems and processes, including soil N dynamics (Holzworth et al., 2014). This model was used most frequently amongst the studies within this dataset, and is frequently used across the scientific literature, however it is not provided in an accessible format for farmers to use. In addition, the model can be modified to increase the accuracy of results, by including add-on modules (as in Vogeler et al., 2022), adding information on the C pool of the site of interest or biochemical composition of the crop residues (as in Vogeler et al., 2019). The APSIM model is used in 2 existing agricultural DSTs: CRAFT (CCAFS Regional Agricultural Forecasting Tool, linked to Wageningen University) (CGIAR, 2014) and CropARM (an Australian tool) (Queensland Government, 2010), however both tools assess crop management scenarios and do not focus on cover crops or nutrient release from cover crops.

The FASSET model (or Farm ASSEssment Tool) is a dynamic farm-scale model which evaluates the impacts of changing management practices, regulations and costs on the farm (Olesen and Hutchings, 2025). The model can also consider field-scale operations such as nutrient flows. On review of the FASSET model, some studies use the model to assess arable systems (including some cover crop assessments), however no existing cover crop DSTs using the model could be found.

The STICS model (Simulateur mulTIdisciplinaire pour les Cultures Standard) is a soil-crop model which simulates soil-plant-atmosphere functioning, simulating crop growth, water and nutrient balances (INRAE, 2022). The STICS model is used within the MERCI DST, which is further discussed in Task 2.

Table 13: Data requirements of models used to predict the amount and timing of nutrient release from cover crop residues. Note these all focused on predicting the amount of N release. n= indicates the individual number of predictions made using each methodology.

Methodology		n=	Data requirements
APSIM model		26	Soil properties (including C content, initial SMN, moisture content), amount of organic material added via crop residues, surface residue quantity, C:N ratio of organic material, rotation management (including sowing density, defoliations, tillage)
Modified APSIM model	APSIM + SMM model	3	APSIM data requirements + simple mineralisation model and SurfaceOM and SoilN modules
	APSIM + C pool data	2	APSIM data requirements + C pool to determine mineralisation based on residue C:N ratio
	APSIM + residue biochemical composition	2	APSIM data requirements + amounts of residue C and N partitioned into carbohydrate/cellulose/lignin pools
FASSET model		6	Daily meteorological data, soil properties, management (inc. sowing, harvesting, tillage, fertilisation), root distribution, root parameters
STICS model		9	SMN, cover crop biomass quantity, cover crop C:N ratio

4.7. Overview of tools available to farmers to estimate the amount of aboveground biomass returned to the soil (Research Question 5)

Information on the tools available to farmers to estimate the amount of aboveground biomass returned to the soil via cover crop residues were included in 9 studies, the majority of which were grey literature referring to specific pieces of equipment. The tools identified and a brief description of these are included in Table 14.

Table 14: Tools available to farmers to estimate amount of aboveground biomass returned to the soil from cover crop residues.

Tool	Description	Is evidence available to evaluate the robustness of the tool
Canopeo app	Take photo using camera phone and upload into app. App determines quantity of crop.	Yes
SamplePoint software	Take photo using digital camera and upload into software. Software determines percentage of crop cover per unit area and nitrogen content in plants.	Yes
NDVI sensors	Sensors can be handheld (e.g., RapidSCAN CS-45, GreenSeeker handheld crop sensor), permanently placed in fields (e.g., Apogee NDVI sensor), attached to tractors (e.g., Falker Flexum) or drones/satellites.	Yes/No (GreenSeeker handheld crop sensor)
Canopy Cover app	Take photo using camera phone and upload into app. App determines percentage canopy cover.	No

Evidence on the robustness of the tool was available for some, but not all, of the options available to farmers. The Canopeo smart phone app (Canopeo App, 2025) was developed in 2015 and has been used in several studies to measure the quantity of vegetation cover, although it should be noted that it can be used for all vegetation types and not specifically cover crops. Chung et al. (2017) and Gonzalez-Esquiva et al. (2017) showed Canopeo to take accurate measurements of vegetation biomass, however Govindasamy et al. (2022) found that measurements were only accurate for some crop types (i.e., cowpea, oats and sorghum) and that taller crops such as corn decreased the accuracy of the measurements. The Canopy Cover app (heaslon, 2024) is another free smart phone app which aims to detect the percentage canopy cover of growing vegetation, however there was no evidence on its use amongst the literature. Govindasamy et al. (2022) also assessed the use of SamplePoint software (Booth et al., 2006), finding that, similarly to Canopeo, the accuracy of the tool depended on the type of vegetation being measured. Perritte et al. (2017) and Yu and Guo (2021) noted the potential for SamplePoint to be accurate and consistent at larger scales, such as the field-scale. Govindasamy et al. (2022) also highlight that the precision of digital image methods, such as Canopeo and SamplePoint, is likely to be affected when a mix of plant populations are present, as may occur when growing a multispecies cover crop mix; they highlight work by Nielsen et al. (2012), stating that SamplePoint provided a good estimation of the ground cover of a species mix of 10 cover crop species, however it is unclear whether the individual cover crop species were distinguished.

One of the most common methods to determine the amount of aboveground biomass is the calculation of NDVI, which provides a measure of the chlorophyll content, or greenness, of the vegetation, and thus its amount, by determining crop reflectance to infrared bands. The Rapid-SCAN CS-45 handheld sensor (Holland Scientific, no date) measures both NDVI and Normalised Difference Red Edge (NDRE), with NDRE suggested to be a more accurate measure at later crop growth stages. Zhao et al. (2020) used the RapidSCAN CS-45 to measure canopy spectral reflectance at 3 infrared bands to calculate vegetation indices, including NDVI, and found that all 3 vegetation indices had a significantly positive linear relationship with the aboveground biomass. The GreenSeeker handheld crop sensor (PTxTrimble, 2025) can also be used in-field to calculate NDVI, however no evidence was available to evaluate the robustness of this tool. Apogee NDVI sensors (Apogee Instruments, 2025) are frequently used amongst the scientific community to measure chlorophyll content and crop biomass (Chen et al., 2021; Mallick et al., 2024; Workneh et al., 2024); these tools are available to farmers, although at a greater cost than the RapidSCAN CS-45 and smart phone apps, and so may be inaccessible. A more user-friendly option for farmers could be NDVI sensors which can be attached to tractors, such as the Falker Flexum active NDVI sensor (Falker, no date), which measures crop reflectance continuously as the tractor drives over the field. It should be noted, however, that there was no evidence to evaluate the robustness of this tool, with its usage only being referenced twice in two Master's dissertations published in Brazil (Lima, 2023; Tavares, 2024). Alternatively, NDVI sensors can be attached to drones or satellites to measure canopy reflectance of larger areas; Miller et al. (2024) compared the performance of 3 sensors – tractor, drone and satellite – for measuring the NDVI of small fields. They reported good agreement between the 3 methods and suggested that the use of drone or satellite imagery provides more accurate results at the field-scale. The performance of NDVI with regards to measuring the biomass of cover crop mixes is more uncertain, however. Vasilikiotis et al. (2015) conclude that "NDVI could be used to estimate the total biomass of single cover crops but not cover crop mixtures", due to the complex canopy structure of cover crop mixes and the fact that some crops, such as grasses and legumes, grow shorter, whilst grains such as rye and oats grow taller. There is very little additional evidence available on the accuracy of NDVI when mixtures of crops growing at different heights are present. In the USA, a large program of work is currently underway by the USDA as part of the PlanMap3D project. The objective of the project isto develop NDVI sensors which can identify cover crop species and produce biomass maps across a field. The technology is currently in development and NDVI mapping is undergoing validation in the field against measurements of cover crop biomass using quadrats.

5. Discussion

This QSR extracted data from 51 studies to understand the scope and volume of the existing evidence on nutrient release from cover crops.

5.1. General observations on cover crop type

Single species winter cover crops were the most common cover crop type across the whole dataset and for each Research Question, followed by multispecies winter cover crops. This was also the case when considering measurements from UK sites only. Cover crops are typically grown over winter, particularly in the UK, to control soil erosion and prevent nutrient leaching (AHDB, 2025b). Legume cover crops grown over winter can also fix N in the soil for use by the following spring crop (AHDB, 2025c). In addition, winter cover crops can be grazed by out-wintered livestock, reducing costs for farmers and providing multiple agronomic benefits (Agrii, 2025). In the UK, single species cover crops are common, however using a cover crop mix provides multiple environmental benefits, including enhanced biodiversity and improved soil health (AHDB, 2025d), and are included in funding schemes such as the SFI, which specifies the inclusion of at least 2 species from 2 or more plant families (covering brassicas, legumes, cereals/grasses and herbs). There are also practical benefits to growing a cover crop mix including different plant families, for instance by providing insurance if growing conditions are not favourable to one of the species in the mix. Across the dataset, the most popular single species cover crops were clover, mustard, oat, radish, rye, ryegrass and vetch, and popular multispecies mixes included oat + radish and ryegrass + clover, with many of these cover crop species being over winter cover crops.

The lack of data on summer catch crops, particularly from sites in the UK, is interesting, as the UK Government's SFI action SOH3 (Multi-species summer-sown cover crop) pays farmers for growing mixed species summer cover crops, with the aim of protecting the soil surface, promoting root growth, and adding organic matter (Defra, 2024b).

Autumn cover crops, particularly single species autumn cover crops, were the next most common cover crop type. None of these measurements were from sites in the UK. Autumn cover crops are not typically grown in the UK, with the growing season of many spring crops extending into August and September, leaving limited time for an autumn cover crop to grow prior to the sowing of a winter cash crop or cover crop. The integration of autumn cover crops into arable rotations is therefore possibly more relevant to temperate countries other than the UK, and therefore would not be relevant to consider if a UK-based DST were to be proposed.

5.2. Cover crop residue biomass

Measurements of cover crop residue biomass return were mainly for aboveground residues, with considerably fewer measurements for belowground biomass residues. Whilst some studies reported both aboveground and belowground biomass residues, it was more common for only the aboveground biomass to be reported. Furthermore, where belowground biomass was reported, the measurements were all for roots, with no measurements of nodules in isolation. The root systems of cover crops will also contribute C and nutrients to the soil and following crop, however, the root to shoot ratios of different species in different environments is variable. Additionally, the C:N ratios, as well as the nutrient concentrations of roots, can be different from that of shoots, and can vary between species (Wendling et al., 2016; Patel et al., 2024). Understanding the root to shoot ratios of cover crops in specific environments could help to define belowground cover crop contributions to nutrient cycling. Furthermore, root: shoot coefficients could be incorporated into DSTs as is carried out for the MERCI model (task 2 report); as it would be impractical for farmers to take accurate measurements of belowground biomass.

The quantity of (aboveground) residue biomass return and the nutrient content of the biomass were the most commonly reported parameters, with a focus on N content as opposed to P, K, sulphur (S) or other nutrients. Whilst N is one of the most limiting factors to plant growth (Leghari et al., 2016), it is currently accepted that there are 14 essential mineral elements for plants (Kirkby, 2023). Under agricultural conditions, N, P and K are the nutrients most frequently added to soils (Raven et al., 1999). The increasing importance of S, due to its decreasing deposition from the atmosphere, means it will be important to monitor its release and provision to the soil. The most useful studies were those that reported biomass quantity, quality (i.e., C:N ratio, N%) and nutrient content together, rather than just 1 or 2 of these parameters; reporting as much information on the characteristics of the cover crop residue returned to the soil will be important if a database is to be created for use in a future UK-based DST.

Multiple tools are available for the determination of the amount of aboveground biomass returned to the soil via cover crop residues, with the accuracy and accessibility of these methods to farmers varying. NDVI is commonly used to determine aboveground biomass, and can be measured on a range of scales. In-field sensors, such as Apogee NDVI sensors, are used commonly throughout the scientific literature, with the accuracy of this equipment being well-evaluated. In-field sensors such as these are unlikely to be accessible to farmers, however, due to the cost and potential infrastructure required. Other options such as handheld NDVI sensors, or sensors that can be attached to tractors, are likely to be a more affordable option, although there is limited evidence available to evaluate the robustness of the latter tool. Smart phone apps are arguably the most accessible tools for farmers, as it is likely they will have access to a device, and can download the apps for free. Canopeo is the most well-known smart phone app to measure crop cover, and is frequently used amongst the literature, with sufficient evidence available to validate its robustness (Chung et al., 2017; Gonzalez-Esquiva et al., 2017). In comparison, the Canopy Cover app is newer, with no data or evidence available to validate the accuracy of its results. The outputs of SamplePoint software are highly appealing to farmers, as the N content of the vegetation is estimated as well as the percentage of crop cover. This would help determine not only the amount of cover crop residue biomass returned to the soil, but it may be possible with further work to develop this into a quick way of estimating the amount of N returned in these residues. Similarly to Canopeo, the software is accessible to farmers, being provided in a free format and requiring a digital photograph of the canopy, which is likely achievable.

Regardless of their availability to farmers, the success of these tools at measuring aboveground biomass of cover crop mixes, rather than single species cover crops, is uncertain. The evidence on the usage of these tools is focused on single species crops, with only a few of these being cover crops, rather than multispecies mixes. Govindasamy et al. (2022) state that the accuracy of Canopeo was reduced when measuring taller crops, such as corn, which could potentially cause an issue if measuring cover crop mixes due to the possible range of growth heights. Similarly, SamplePoint has been proven to be successful when measuring single species (cover) crops, but not when measuring cover crop mixes (Govindasamy et al., 2022) – again due to the range of heights present. Measurements of NDVI are limited when cover crop mixes are present (Vasilikiotis et al., 2015).

5.3. Nutrient release

Across the dataset, there were more measurements of nutrient release (Research Questions 2 and 3) than predictions of nutrient release (Research Question 4). The majority of the studies included in the QSR were field studies, thus providing measurements, whereas predictions of nutrient release are likely to require modelling, which is outside the scope of many field studies. Around 50 papers per year are published on the topic of ‘cover crop residue and nutrients’ (Web of Science, 2025); research in this field is therefore likely to prioritise building the evidence base with measurements from field and laboratory studies, with modelling studies potentially becoming more common in the future when there is sufficient evidence to enter into models.

Similar to measurements of the nutrient content of cover crop residue biomass, the nutrient release from cover crop residues to the soil and the availability of these nutrients to the following cash crop focused on N, with fewer measurements of P and K. A considerable proportion of agricultural research has focused on the interactions between crop and soil N, and the use of fertilisers, as N can be particularly limiting for crop growth and is vulnerable to being leached from the environment (Defra, 2025b). Furthermore, there has been a drive to establish methods which can reduce synthetic fertiliser use in agriculture, including the use of N-fixing legume cover crops, in order to reduce the associated environmental risks (Oliveira et al., 2021).

The evidence on nutrient release from cover cropsfocused more on the amount of nutrients that were released, rather than the timing. This is possibly due to estimates of nutrient release timing requiring multiple measurements to be taken over time, which may be outside the scope of many field studies. Understanding the amount of nutrients released may require only 1 or 2 measurements of the cash crop, however. Understanding the timing of nutrient release from crop residues is crucial for best matching nutrient supply with crop demand, and avoiding excess nutrient application which could be lost via leaching or volatilisation. The most common time for the majority of nutrient release to occur was within several days of cover crop destruction. This occurred in 30 % of the observations as a whole, rising to nearly 100 % in the available UK data. The remaining measurements showed that the category with the highest number of measurements was studies which reported the majority of N to be released from cover crop residues immediately (i.e., within a few days) after cover crop destruction (30 % of the findings). The remaining measurements suggesting that most of the N was usually available within 3 weeks to 2 months of destruction. The timing of nutrient release from crop residues is determined by the rate of residue decomposition, which in turn is affected by its biochemical composition (i.e., C:N ratio) and environmental factors such as precipitation, temperature, soil moisture content, soil C:N ratio, and the composition of microbial communities in the soil (Grzyb et al., 2020; Mishra et al., 2024). Leguminous residues, for example, generally break down faster than non-leguminous residues, as they have a lower C:N ratio and are more easily decomposed by soil microbes, and thus have faster nutrient release (da Silva et al., 2021; Lussich et al., 2024). It is generally advised that cover crops should be destroyed at least 6-8 weeks before the planned drilling date of the following crop in order to avoid a reduction in yield and to allow the cover crop residue to break down (Cover Crops Guide, 2025). On the other hand, the SFI action SOH2 (Multi-species spring-sown cover crop) states that farmers must not destroy a well-established cover crop more than 2 weeks before the planned drilling date of the next crop; whilst the CSAM2 states that winter cover crops must not be destroyed more than 6 weeks before establishing an early sown spring crop (Defra, 2024c), and AHDB suggest leaving 1-2 weeks between destroying a cover crop and drilling the next crop (AHDB, 2025e). Furthermore, some water companies increase the amount paid to farmers if they destroy their cover crops later in the season (e.g. Portsmouth Water S. Deacon Pers. Comm.). The method of cover crop destruction can also influence the timing of nutrient release and availability; the NiCCs project conducted by ADAS found that winter cover crop destruction using glyphosate increased SMN relative to mechanical destruction, and that the greater and earlier availability of SMN would have benefitted the following spring cereal crop (Thorman et al., 2024). As the findings from the QSR indicate that because N release from cover crops can occur rapidly (e.g., typically within several days or 3 weeks after destruction), understanding the amount of excess rainfall following the destruction of a winter cover crop will be critical when evaluating the amount of N available to the following cash crop. For instance, in situations of high excess winter rainfall, the N released from the cover crop could be leached beyond the rooting depth of a spring crop, and therefore not available for uptake.

The amount and/or timing of nutrients added to the soil from cover crop residues were primarily based on measures of SMN and soil nitrate-N, both of which are established methods for determining N release (Li et al., 2015; Boldt et al., 2021; Koch et al., 2022; De Notaris et al., 2025). Verzeaux et al. (2016) use total N to determine the amount of nutrients added to the soil from cover crop residues; the amount of N that will be added to the total N pool from cover crop residues is likely to be very small in relation to the entire total N pool, and so these measurements should be treated with caution.

For the data relevant to Research Questions 2 and 3, there were more individual measurements of nutrient release from cover crop residues to soil (Research Question 2) than nutrient release from cover crop residues that was available to the following cash crop (Research Question 3). Similar to the lack of studies predicting nutrient release, many experimental studies are limited by time and funding, and so it may be the case that the studies did not include the scope to grow and measure a following cash crop. Across the dataset, the most popular following crops were spring barley (from both in the UK and elsewhere) and sugar beet (outside of the UK) – with the majority of cover crops being winter cover crops, it is therefore logical that these are followed by spring cash crops. Some studies did not report the type of following cash crop (Thorup-Kristensen and Dresboll, 2010; De Notaris et al., 2019; Vogeler et al., 2019; Cottney et al., 2021; Vogeler et al., 2023), although this information would be beneficial to provide context to each measurement. Future work to provide an understanding of how N availability contrasts between early and late spring sown crops (i.e., maize or potatoes) may be of relevance, particularly as the results of the QSR indicate that some N can be available to the following crop for several months after cover crop destruction.

As highlighted, measurements of nutrient release from cover crop residues available to the following cash crop (Research Question 3) were primarily focused on N release, with few measurements of the amount of K available to the following crop and no measurements of P availability to the following crop. The amount of N released from cover crop residues mainly ranged between 0-30 kg N/ha, supplied via a range of crop residue types. The AHDB Nutrient Management Guide (RB209) highlights that nutrient release from cover crops destroyed at the end of February is more predictable –“sufficient to increase the SNS by up to two Indices” – whereas the amount of nutrient release from cover crops destroyed later in the spring is more difficult to determine (AHDB, 2023a). In addition, the N fertiliser requirement for an SNS increase by up to two Indices is highly variable by crop type and is driven by the overall N requirement of the crop. An increase in SNS by up to two Indices (e.g., from Index 0/1 to 2/3) would equate to a reduction in N fertiliser requirement for spring barley of between 50-80 kg N/ha, whereas the reduction for sugar beet would be only 20-40 kg N/ha. Overall, sugar beet has a low N fertiliser requirement (with an N max of 120 kg N/ha) which is in part due to the ability of the crop to scavage N later in the season (BBRO, no date). It is critical not to over apply N fertiliser to sugar beet as this can increase the levels of amino-N impurities, which can negatively impact sugar extraction and quality

(BBRO, no date). Notably, none of the UK studies reviewed assessed the amount and timing of N available to sugar beet. However, data from other temperate countries showed that N supplied to the following crop ranged between 0-80 kg N/ha; which is up to double the amount indicated in The AHDB Nutrient Management Guide (RB209).

The amount of N supplied by cover crop residues is influenced by the cover crop species, residue characteristics (i.e., N%), amount of biomass produced, and the destruction, and possibly incorporation, method (Lu, 2020). The availability of these nutrients is further controlled by the residue C:N ratio and environmental conditions (i.e., soil temperature and moisture) (Grzyb et al., 2020; Mishra et al., 2024). An exploration of the interaction between these factors and N availability to cash crops was outside of the scope of the QSR, however it would be important to consider these in the development of a DST supporting nutrient management planning for arable rotations with cover crops. The AHDB Nutrient Management Guide (RB209) does not provide guidance on the potential release of P and K from cover crop residues; this data gap also being present within the QSR database highlights the need for more research on this topic in the future. Field measurements of the amount of nutrients from cover crop residues available to the following cash crop were mainly determined by measuring the nutrient uptake of the cash crop grown in soil both with and without a preceding cover crop (n=56 individual measurements from 5 studies) or by calculating the fertiliser replacement value (n=76 individual measurements from 8 studies). Seventeen of the 18 studies relevant to Research Question 3 included an unfertilised, ‘0N control’ treatment, meaning that any ‘background’ N in the soil would have been accounted for, enhancing the robustness of the results.

Predictions of nutrient release from cover crop residues also focused more on the amount of nutrients than the timing of nutrient release (Research Question 4). Predictions were only made for N release, with no predictions of P or K release, and were made using 3 models: APSIM, FASSET and STICS. The APSIM and FASSET models require input data on soil properties, residue addition and field management practices, whereas the STICS model does not require such precise inputs. All 3 models require a measurement of SMN, although PMN and AAN are not mentioned. Amongst the literature, the APSIM model is used the most frequently, with some researchers modifying the software to gain more accurate data. APSIM is used in 2 agricultural DSTs, and STICS is used in the MERCI DST; whilst the models themselves may be inaccessible to farmers due to the prior knowledge and time required, their integration into existing DSTs offers an accessible way for farmers to aid their nutrient management planning (see Task 2 report for further details).

5.4. The suitability of decision support methodologies for other potential soil nutrient building options aside from cover crops (companion crops, undersown maize, (legume) fallows, herbal leys) (secondary Research Question)

The literature search conducted as part of the QSR resulted in no data on companion crops, undersown maize, legume fallows, or herbal leys, and thus conclusions cannot be drawn on whether decision support methodologies are suitable for these nutrient building options. A report conducted by ADAS in 2025 on nitrate leaching from herbal leys and legume fallows found no data for legume fallows, and only 14 relevant papers on herbal leys or multi-species swards (Rollett, 2025). A separate research project would be required to fully evaluate the suitability of decision support methodologies for soil nutrient building options other than cover crops, with dedicated search terms to identify this data, in order to first review the existing data on these topics, and then establish whether decision support methodologies would be appropriate.

6. Conclusion and knowledge gaps

This QSR reviewed the existing scientific evidence on the quantity, nutrient content and quality of cover crop residues and the tools available to farmers to evaluate biomass return, and the amount and timing of nutrient release from cover crop residues to both the soil and the following cash crop and the methodologies used to predict this.

Within the evidence base, the UK was the country with the highest number of measurements, although only winter cover crops were grown at these sites. Summer and autumn cover crops (and winter cover crops) were measured in other temperate climates, and had a lower sample size across the whole dataset. The most amount of data was available in relation to Research Question 1, although this was focused on the characteristics of aboveground cover crop residue biomass – which can be measured by farmers using a range of apps, sensor and NDVI methodologies – with data on belowground biomass and the P and K content of cover crop residues lacking in comparison. The database centred around N return to soil and the availability of this to the following cash crops, with considerably less data on P and K return to the soil and P availability to the following cash crop, with no data on the amount of K available to the following cash crop. The QSR found that 30 % of studies reported the majority of N from cover crop residues to be released immediately after cover crop destruction (i.e., within several days). Furthermore, the database had a high number of measurements on nutrient release, but considerably fewer predictions of this, with the predictions that were available made primarily using the FASSET, APSIM and STICS models, the latter of which have been incorporated into existing DSTs.

The following data would be beneficial to obtain to build and strengthen the future evidence base on nutrient release from cover crop residues:

- Increased replication of measurements by cover crop residue type.
- More data for summer and autumn cover crops – although the latter is potentially less relevant to a UK context.
- More measurements of belowground biomass characteristics.
- Accounting for the residue quantity, quality (i.e., N%, C:N ratio) and nutrient content together, and considering P and K as well as N content, when characterising cover crop residue biomass.
- If possible, consider the timing of nutrient release as well as the amount – both to the soil and to the following cash crop, and consider P and K as well as N content.

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8. Appendices

Table 15: Management information for autumn cover crops included in the dataset. nd indicates that no data were available.

Cover crop type	Planting date	Destruction date	Following crop	Soil type	N available to following crop (kg/ha)	Reference
Clover	August	November, left on surface until spring and incorporated	nd	Silt loam	nd	Gentsch *et al.* 2021
Multispecies mix (>5 species)						
Mustard						
Mustard + phacelia + oat + clover mix						
Oat						
Phacelia						
Vetch	August	October	Spring barley	Loamy sand	31-60	Li *et al.*, 2015a
Mustard	July/August	Between September and November	nd	Loamy sand	nd	Thomsen *et al.*, 2016
Radish (n=10 individual measurements)						
Ryegrass (n=2 individual measurements)						
Radish	August	October	Spring barley	Loamy sand	0-30	Li *et al.*, 2015b
Vetch						
Ryegrass	May	February	nd	Sandy loam	31-60	Vogeler *et al.*, 2023
Ryegrass + clover mix						
Fiddleneck (n=2 individual measurements)	August	November	nd	Clay	nd	Kucerik *et al.*, 2024
Fiddleneck (n=2 individual measurements)						
Mustard (n=2 individual measurements)						
Mustard (n=2 individual measurements)						
Pea (n=2 individual measurements)						
Pea (n=2 individual measurements)						
Rye (n=2 individual measurements)						
Rye (n=2 individual measurements)						
Safflower (n=2 individual measurements)						
Safflower (n=2 individual measurements)						
Buckwheat	August	November	nd	Sandy loam	0-30	Hansen *et al.*, 2021

Cover crop type	Planting date	Destruction date	Following crop	Soil type	N available to following crop (kg/ha)	Reference
Ryegrass						
Clover						
Lupine						
Radish					nd	
Ryegrass						
Sorrel						
Vetch						
Oat (n=2 individual measurements)						
Ryecorn (n=2 individual measurements)	June/August	December	nd	Silt loam	nd	Malcolm *et al.*, 2021
Triticale (n=2 individual measurements)						
Mustard (n=4 individual measurements)						
Phacelia (n=2 individual measurements)	August	October/November	nd	Silty clay	nd	Liu *et al.*, 2015
Radish (n=12 individual measurements)						
Buckwheat						
Lupine						
Multispecies mix (>5 species)						
Mustard	August	November	nd	Sandy loam	nd	Selzer *et al.*, 2021
Phacelia						
Radish						
Ryegrass						

Table 16: Cover crop types included in dataset and number of individual measurements for each cover crop type of relevance to each Research Question.

Cover crop type	Group	Q1	Q2	Q3	Q4
		n=			
Average of individual non-legume crops	Non-legume	5	3	0	3
Average of individual legume crops	Legume	3	3	0	3
Average of individual legume/non-legume crops	Mix	0	0	0	0
Barley	Cereal	3	0	1	0
Bean	Legume	2	1	1	0
Buckwheat	Polygonum	6	4	1	0
Chicory	Asteraceae	8	2	0	2
Clover	Legume	29	16	14	0
Cocksfoot	Grass	6	0	0	0
Corncockle	Caryophyllaceae	1	1	1	0
Fiddleneck	Boraginaceae	4	0	0	0
Grass	Grass	0	0	0	1
Lentil	Legume	1	0	0	0
Linseed + phacelia + sunflower + buckwheat mix	Non-legume mix	2	0	0	0
Linseed + vetch + phacelia mix	Mix with legumes	2	0	0	0
Lupin	Legume	3	3	1	0
Multispecies mix (>5 species)	Mix – not specified	8	7	0	3
Mustard	Brassica	32	12	5	7
Mustard + phacelia + oat + clover mix	Mix with legume & brassica	6	1	0	0
Mustard + vetch mix	Mix with legume & brassica	4	4	0	4
Oat	Cereal	35	26	14	0
Oat + buckwheat + phacelia mix	Non-legume mix	0	3	2	0
Oat + clover mix	Mix with legumes	10	3	0	0
Oat + phacelia mix	Non-legume mix	2	0	0	0
Oat + phacelia + clover mix	Mix with legumes	3	3	0	0
Oat + radish mix	Non-legume mix	20	12	0	0
Oat + radish + phacelia mix	Non-legume mix	2	0	0	0
Pea	Legume	5	1	1	0
Phacelia	Boraginaceae	17	4	2	0
Phacelia + buckwheat mix	Non-legume mix	3	3	0	0
Phacelia + clover mix	Mix with legumes	3	3	0	0
Phacelia + radish mix	Non-legume mix	5	6	2	0
Plantain	Forb	4	4	4	0
Radish	Brassica	68	43	22	5
Radish + phacelia + buckwheat mix	Non-legume mix	3	1	0	0
Radish + vetch mix	Mix with legumes	7	5	2	0
Rape	Brassica	9	6	2	4
Rape + vetch mix	Mix with legume & brassica	4	4	0	4
Rye	Cereal	31	23	18	0
Rye + vetch mix	Mix with legumes	1	1	1	0

Cover crop type	Group	Q1	Q2	Q3	Q4
		n=			
Ryecorn	Cereal	2	2	0	0
Ryegrass	Grass	42	22	10	6
Ryegrass + chicory + clover mix	Mix with legumes	6	6	4	0
Ryegrass + clover mix	Mix with legumes	22	8	16	4
Ryegrass + plantain mix	Non-legume mix	4	4	4	0
Ryegrass + plantain + clover mix	Mix with legumes	4	4	4	0
Safflower	Asteraceae	4	0	0	0
Sorrel	Polygonum	1	1	0	0
Triticale	Cereal	2	2	0	0
Turnip	Root vegetable	3	1	3	0
Unspecified brassica	Brassica	0	0	0	1
Unspecified legume	Legume	0	0	0	1
Unspecified legume/non-legume mix	Mix with legumes	18	0	0	0
Vetch	Legume	45	35	20	0
Vetch + oat mix	Mix with legumes	4	4	0	0
Vetch + oat + radish mix	Mix with legumes	4	4	0	0
Westerwolds	Grass	6	1	1	0