December 2023

Annual Project Report

On-farm trials at

Strategic Cereal Farm East

(harvest 2023)

AHDB Cereals & Oilseeds is a part of the Agriculture and Horticulture Development Board (AHDB).

CONTENTS

1. Introduction

Host Farmers: Cousins Brian (pictured) and Patrick Barker
Location: E.J. Barker & Sons, Suffolk
Duration: 2017–2023

AHDB Strategic Cereal Farms put cutting-edge research and innovation into practice on commercial farms around the UK. Each farm hosts field-scale and farm-scale demonstrations, with experiences shared via on-farm and online events to the wider farming community.

E.J. Barker & Sons is a family farm partnership and contracting business that dates to 1957. The family owned 513ha arable farm business is farmed on a traditional 12-year rotation, incorporating winter wheat for feed, herbage grass seed and break crops of spring barley, beans, oilseed rape or linseed.

Environmental considerations are crucial to the running of the business and are a key factor in all the decisions made on the farm.

2. Managed lower inputs (work package 1)

Trial leader: Will Smith, NIAB
Start date: 01 September 2022
End date: 31 August 2023

2.1. Headlines

- Disease levels were consistently low across treatments throughout the duration of the trial, with only septoria tritici observed early in the season and below 5%
- Despite this, the three-spray programme was associated with improved yields, although the level of each input was largely irrelevant
- Due to the low disease levels and only small yield responses, the majority of treatments returned a negative return on investment in this season

2.2. What was the challenge/demand for the work?

Loss of chemistry and fungicide resistance means that we need new ways to manage cereal diseases. AHDB projects support farmers and agronomists to manage cereal diseases. For example, fungicide performance research provides information on the effectiveness of active ingredients and modes of action and the Recommended Lists (RL) can help farmers identify the best varieties for the disease profiles on the farm. This trial tested the cost-benefit of high and low-cost input programmes.

2.3. How did the project address this?

The trial used two input levels and seven fungicide timings, which was made up of each standard timing applied in isolation and in combination which each other. This design enables the assessment of the relative contribution of each application within a programme to disease control and crop yield.

The interactions between input levels across a full three-spray programme was also tested with varying levels of inputs at each timing. This was, in response to previous years, where a full programme was necessary to protect the crop, but there was a lack of understanding as to how to tailor the input levels at each treatment timing. Products used were based on field observations and were not set at the beginning for the season.

The full treatment list is published in Table 1. The fungicide products and rates used is published in Table 2.

The field-scale trial had plot dimensions of 30m x 50m, with all applications made by the host using best application practice. Other applications were standardised across plots, including seed rate, fertilisers, plant growth regulators (PGRs) and herbicides.

The crop of winter wheat (cv. LG Tapestry) was drilled on 28 September 2022. As in previous seasons, the variety was chosen to provide robust resistance to the key foliar diseases that are commonly observed in the UK. Although not on the AHDB UK recommended list for winter wheat, LG Tapestry (a Group 4 soft feed wheat) exhibits good resistance to yellow rust (8.0) and brown rust (7.8), both key diseases at this site, with moderate resistance to septoria tritici (5.8). It provides a strong base from which inputs could be managed.

Table 1. Fungicide treatment list

Treatment	Input level	Application timings
1	Untreated	
2	Low	T1 Only
3		T2 Only
4		T3 Only
5		T1 + T2
6		T1 + T3
7		T2 + T3
8		T1, T2 + T3
9	High	T1 Only
10		T2 Only
11		T3 Only
12		T1 + T2
13		T1 + T3
14		T2 + T3
15		T1, T2 + T3
16	Interaction	Low-Low-High
17		Low-High-Low
18		Low-High-High
19		High-High-Low
20		High-Low-Low

Table 2. Products used and rates of applied products

Timing	Low		High		Application date
	Product	Rate (l/ha or kg/ha)	Product	Rate (l/ha or kg/ha)	
T1	Sparticus Xpro	1.25	Verydor XE	1.0	26/04/2023
			Stabilan 750	1.0	
T2	Ascra Xpro	1.20	Verydor XE	1.5	18/05/2023
			Calibra Carbo	1.0	
T3	Tubosan	0.50	Firefly 155	1.0	08/06/2023
			Epsotop	3.0	

Sparticus Xpro (Bayer CropScience) contains Bixafen (75 g/l), prothioconazole (100 g/l) and tebucaonazole (90 g/l); Verydor Xpro (BASF) contains fluxapyroxad (47.5 g/l) and mefentrifluconazole (100 g/l); Tubosan (Belchim Crop Protection) contains tebuconazole (250 g/l); Firefly 155 (Bayer CropScience) contains prothioconazole (110 g/l) and fluoxastrobin (45 g/l).

Weather

Across the growing season, the autumn was warmer than the long-term average, with mostly lower rainfall, excluding a very wet November, which was characterised by several intense rain showers. The spring was marginally cooler than the long-term average, and generally drier. Rain came in March, which may have contributed to the early observations of disease, but the drier conditions that followed, particularly in June, slowed the movement of disease through the canopy. The T1 application coincided with warming temperatures and a period of very low rainfall.

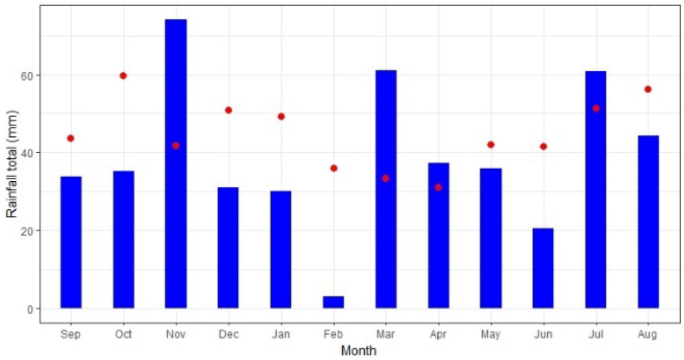
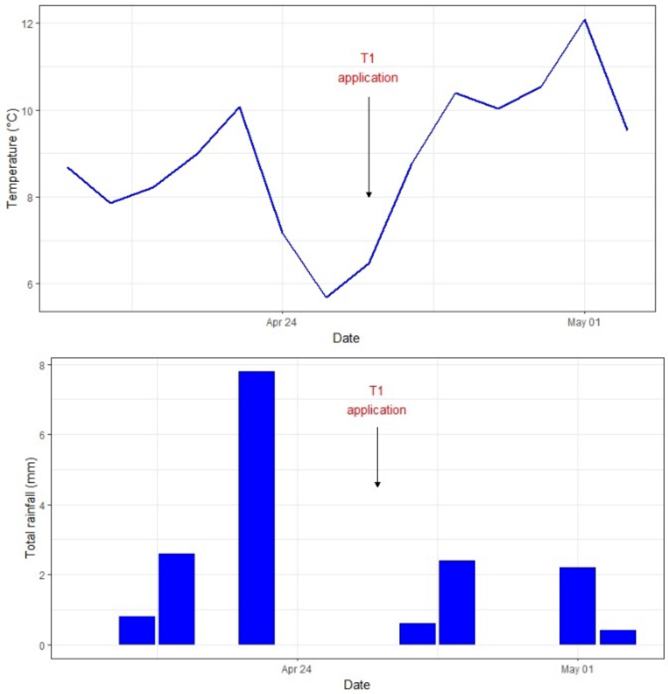


Figure 1. Rainfall across the growing season, summarised by month. The red diamonds indicate the long-term (10-year) average.



Figures 2a and 2b. The conditions around the T1 application in the 2022–23 season. Average daily temperature (top) and total daily rainfall (bottom)

2.4. Results

Disease incidence and severity

Septoria tritici was detected in the lower leaves at the time of the T1 application. However, at subsequent assessments, the disease was not moving into the upper canopy, even in the untreated plots. Leaf layer assessments carried out throughout this period continued to observe limited (<5%) disease present on either leaf 1 or 2 in any plots. In previous years, late infection of yellow rust and brown rust were observed, however in this season, neither materialised.

Figure 3. Images from the untreated plots across site visits – 26/04/2023 (top left), 23/05/2023 (top right) and 30/06/2023 (bottom)

Input level

With observed disease levels so low at all assessment timings, it was not possible to evaluate the role of input level in respect to disease control in this trial.

Crop performance

The key indicator of crop performance was final crop yields. The trial had an average yield of 10.15 t/ha, which is above the long-term performance of the field as a second wheat and is representative of the farm's performance in this season.

In this season, there were no significant yield increases (compared to the untreated) in any treatment, although two treatments yielded significantly less. Considering an absence of differences in the levels of disease infection, this is an unsurprising result. In previous years, we have observed significant yield differences in the absence of disease, which gave some evidence for greening effects from fungicides, however this has not been replicated in this season.

Table 1. Average crop yield for the low and high input programmes. Yields followed by a different letter indicates significance (p<0.01)

Timing	Low input		High input	
Untreated	10.21	abcde		
T1	10.14	bcdef	9.53	fg
T2	9.62	efg	10.10	bcdef
T3	10.18	abcdef	9.02	g
T1 + T2	9.88	def	10.51	ab
T1 + T3	10.40	abcd	10.40	abcd
T2 + T3	9.92	cdef	10.33	abcd
T1, T2 + T3	10.45	abc	10.74	a

When pooled together, a full programme, on average, out-yielded the single or double application treatments by 0.4 t/ha, so the evidence continues to support the use of three-spray programmes, which is common commercial practice. Therefore, a realistic strategy to reduce inputs is to tailor each timing according to observations in the crop, information from decision support tools or latent disease testing.

Table 2. Average crop yield for the full programmes (T1, T2 & T3). These treatments were sub-set and reanalysed using a one-way ANOVA. Yields followed by a different letter indicates significance (p<0.01).

Timing	Yield (t/ha)	
High-High-High	10.74	a
Low-Low-Low	10.45	a
Low-Low-High	10.62	a
Low-High-Low	9.53	b
Low-High-High	10.37	a
High-High-Low	10.15	ab
High-Low-Low	10.94	a

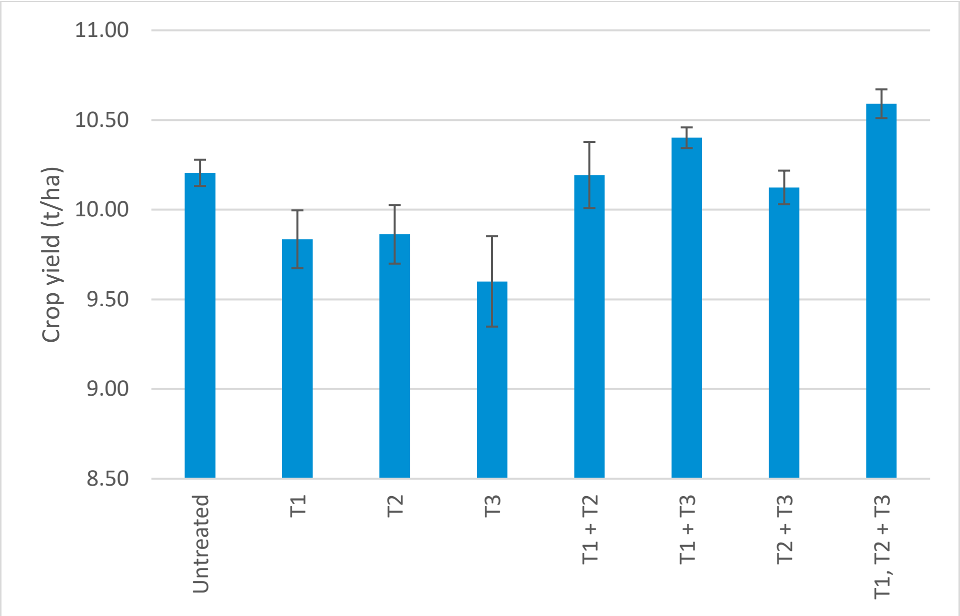


Figure 4. Crop yields pooled across input levels for the 2023 season. Error bars represent the standard error of the mean

A full spectrum of grain analysis was carried out by NIAB Analytical Services, with no significance differences observed for any of the grain characteristics tested, including protein content, Hagberg Falling Number, Specific Weight, Thousand Seed Weight or grain size fractions. If differences had been present, this information would have been used to adjust grain price according to market specification.

Gross margin analysis

Yield is often the most reported metric from field trials, but it is less often used to inform the gross margin of the tested treatments, which is from the business aspect the more important metric.

Gross margins of cropping systems are strongly influenced by the crop yield. Often only small increases in yield are required to justify expenditure in a crop. In this trial, most of the treatment programmes resulted in no yield improvement, despite investment in fungicides. Where yields were improved, these increases were small, and so only a single treatment returned a better gross margin than the untreated.

Despite these findings, we do not suggest that leaving varieties with apparently high disease resistance in low-risk areas of the country untreated is an appropriate strategy in all years. Even with resistant varieties, the disease risk varies with weather and is largely unknown at the time of fungicide application. Instead, we advocate a risk-based strategy, based on the risk of the crop being exposed to disease, and the ability of the crop to resist or tolerate disease. Each grower or agronomist has their own relationship to risk, particularly when considered in a professional environment.

Variety choice and drilling date have the largest effect on appropriate fungicide spend and choosing a disease resistant variety can give an opportunity to reduce fungicide spend by as much as 50%. Experience, together with data available from on-farm trials will further drive the decision-making process, in terms of the requirement of investment into programme spend to protect and enhance yield. An analysis of Recommended Lists (RL) data, adjusted for real world figures, would indicate that if you spend 50% of the expected additional income from your fungicide programme then you would expect to have a Return on Investment (ROI) of >100% on 95% of occasions. This should provide confidence and guidance to growers who set out to reduce inputs. Finally, be prepared to adjust as conditions change and the observed symptoms change. In previous iterations of this trial, the most important application was T3, where good control of yellow rust was needed to fully protect yields.

Table 3. Suggested maximum spend, including application cost, for a range of varieties (wheat price of £186/t)

Variety	Adjusted yield response (t/ha)	Maximum permissible spend (£/ha)
Skyfall	2.38	221
KWS Firefly	1.67	155
LG Skyscraper	1.41	131
KWS Siskin	0.99	92
KWS Extase	0.61	56

Previous results have suggested that a three-spray programme, but with a lower level of input at each timing, as the best strategy, as disease infection can occur throughout the season, and there is a lack of effective curative actives. How this is delivered in practice on the most resistant varieties may require some imagination to ensure that appropriate products are used, but there may be greater scope to cut timings, if crop inspections indicate limited disease presence, or where use of leaf testing for pre-symptomatic disease has been carried out.

For this trial, the variety was LG Tapestry, which by this metric has a maximum permissible spend of £135.60/ha. This was approximately the cost of the full, low-input programme. This season fell into the 5% of years, with this programme not delivering a sufficient yield response to recover the cost of the fungicide programme. However, in the context of the trial, this was one of the better performing treatment programmes. The evidence indicates suggests that a three-spray programme, adjusted as the season progresses is the best option. The best performing treatment programme was a combination of high input at T1, reduced to a lower input at T2 and T3, as disease levels remained low.

2.5. Action points for farmers and agronomists

How brave can we be? From this season, and that of the previous two seasons, it suggests much braver, particularly when it comes to disease management.

We have demonstrated that in East Anglia, where the risk of disease is not at the levels regularly experienced in the rest of the country, it is possible to significantly moderate fungicide use when the other elements of an integrate pest management (IPM) strategy are maximised.

In all seasons, a variety with good levels of disease resistance was used, and drilling date was delayed into late September or early October. In this season, the use of LG Tapestry showed a willingness to push the system, as a variety with some of the lowest fungicide response figures available in the feed wheat category.

The more important question is: if this is a possibility, then why aren't fungicide programmes being reduced in intensity? This is largely related to the perception of risk – of what could happen without the use of protective chemistry, representing a financial risk.

Yield is the biggest driver of profitability with even a small increase in yield (0.5 t/ha) representing a possible £90–130/ha uplift in income. However, if the financial cost outweighs the ROI benefit, then the net gain is negative.

The use of varieties with more robust disease ratings should encourage the moderation of fungicides, and a rule of thumb of spending no more than 50% of the yield response from the Recommended Lists (RL) trials can be applied. By no means does this guarantee returns on this investment, but it should help to maximise margins in the years when input was required and help to curtail unnecessary spend.

3. Water quality and cover crops (work package 2)

Trial leader: Nathan Morris, NIAB

Start date: 1 September 2017

End date: 31 August 2023

3.1. Headlines

- Improving water quality on farm has many interactions in terms of management (cultivation and rotation)
- Over-winter rainfall can significantly affect drain water concentrations
- Approximate average daily losses of nitrate from field drains varied from 0.1 to 1.8 kg nitrogen/day, equating to £0.20 to £3.70/day (based on AN fertiliser at £2.00/kg N)
- There appears to be a linear decline in nitrate losses through tillage, decreasing tillage intensity (i.e. low soil disturbance) reduced nitrates by 55–66% compared to ploughing
- Grass, oilseed rape, winter barley and cover crops can reduce nitrate losses by up to 50%, although this is dependent on previous cropping
- Cover crops can be part of a farm strategy that reduce drain water nitrate concentrations
- However, cover crops may release nitrate in subsequent seasons and subsequent cropping may not utilise available nitrogen, leading to losses to water

3.2. What was the challenge/demand for the work?

Using cover crops to mitigate against nitrate losses in water can be successful. However, nitrogen release in the following crops during the rotation is trickier to predict and can be affected by the climatic conditions. The carbon-to-nitrogen (C:N) ratio of the residues is one of the main factors influencing the dynamics of mineralisation of the nitrogen accumulated by the cover crops.

In-season crop management, including nitrogen management according to crop growth, nutritional requirements and crop yield potential should be monitored with applications adjusted where required to minimise losses to water.

3.3. How did the project address this?

The trials examined the role of cover crops in reducing nitrate leaching losses over six-years. Over this period, a comprehensive dataset has been collected, including soil and crop assessments, which enabled the examination of the role of cover crops to retain nutrients and reduce the risk of nutrient losses through field drains. This included the sampling of water removed by the field drains under different crops establishment systems and soil types.

A wider dataset, including water quality samples, have been collected from a number of field drains across the farm between 2017 to 2022. These water samples have been analysed for a wide range of nutrient and pesticide concentrations (Table 4) by Essex and Suffolk Water. Alongside this, details on soil type, cultivation and crop type were used to improve the understanding of what management factors affect the concentrations in field drains. This information was used alongside weather data (rainfall) and other farm records to understand the risks to leaching from direct management interventions. In addition, other work at the farm has reported on marginal land, looking at yield performance across the farm. This information will also help to interpret where losses to the field drains, in particular, nitrogen may have occurred in areas or situations where lower yield occurred.

Across the farm, over the five-year period, between 302 and 341 water samples were collected and analysed to determine concentrations of parameters detailed in Table 4. The results for the whole farm are shown in Table 5 (pesticide samples) and Table 6 (nutrient samples). Results are traffic-light coloured to indicate the number of parameters above the Prescribed Concentration or Value (PCV). With regards to pesticide concentrations, the ones found above the PCV value included (in order of occurrences); propyzamide, MCPA, pentachlorophenol, triclopyr, bentazone, metaldehyde, 2,3,6-trichlorobenzoic acid, clopyralid, dichlorpropand and MCPB. Other pesticides tested all resulted in no samples over 0.1ug/l (mimimumn detectable limit). Some parameters tested are no longer on the UK Pesticide Approval database and cannot be used on farm (e.g. bromoxynil). However, residues can persist in soil for several years.

For nutrient samples above the PCV value (in order of occurrences) included nitrate, suspended solids, phosphorus, zinc, boron and manganese. The only nutrient, across the farm not to have tested over the PCV limit was sulphate. Phosphate has no agreed PCV limit but guidance recommends levels to be below 45 mg/l.

Table 4. Parameters measured and Prescribed Concentration or Value (PCV) for Drinking Water Standards

Parameter	Standard (PCV)
2,3,6-trichlorobenzoic acid *	0.1 µg/l
2,4,5-T *	0.1 µg/l
2,4-D	0.1 µg/l
2,4-DB *	0.1 µg/l
Benazolin *	0.1 µg/l
Bentazone	0.1 µg/l
Boron	1.0 mg/l
Bromoxynil *	0.1 µg/l
Chloridazon *	0.1 µg/l
Clopyralid	0.1 µg/l
Dichlorprop	0.1 µg/l
Fenoprop	0.1 µg/l
Ioxynil *	0.1 µg/l
Lenacil	0.1 µg/l
Manganese	50 µg/l
MCPA	0.1 µg/l
MCPB	0.1 µg/l
MCPP *	0.1 µg/l
Metaldehyde *	0.1 µg/l
Nitrate	50 µg/l
Pentachlorophenol *	0.1 µg/l
Phosphorus (total)	No legal limit (45 mg/l guidance)
Picloram	0.1 µg/l
Propyzamide	0.1 µg/l
Sulphate	250 mg/l
Suspended solids	4 NTU
Triclopyr	0.1 µg/l
Zinc	5.0 mg/l

mg/l – milligrammes per litre or parts per million, µg/l – microgrammes per litre, NTU – Nephelometric Turbidity Units.*Indicate products that are no longer on the UK Pesticide Approval database

Table 5. Pesticide tested from field drain samples for winters 2018–2022 by AHDB and Essex & Suffolk Water

Pesticides tested for	2,3,6-trichlorobenzoic acid	2,4,5-T	2,4-D	2,4-DB	benazolin	bentazone	bromoxynil	chloridazon	clopyralid	dichlorprop	
	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	
Samples over 0.1ug/l	1	0	0	0	0	4	0	0	1	1	
Samples below detectable limit	319	320	320	320	320	298	319	319	318	310	
Samples with no trace	0	0	0	0	0	0	0	0	0	0	
Total Samples Taken	**320**	**320**	**320**	**320**	**320**	**302**	**320**	**319**	**319**	**311**	
Pesticides tested for	fenoprop	ioxynil	lenacil	MCPA	MCPB	MCPP	metaldehyde	pentachloro phenol	picloram	propyzamide	triclopyr
Result Units in	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l
Samples over 0.1ug/l	0	0	0	19	1	0	2	10	0	34	10
Samples below detectable limit	308	309	320	297	319	316	339	310	320	279	310
Samples with no trace	0	0	0	0	0	0	0	0	0	0	0
Total Samples Taken	**308**	**309**	**320**	**316**	**320**	**316**	**341**	**320**	**320**	**313**	**320**

Note: Colours denote levels of samples over PCV (Green = None; Amber = Some; Red = High).

Table 6. Nutrients tested from field drain samples for winters 2018–2022 by AHDB and Essex & Suffolk Water

Nutrients tested for	Suspended solids	Nitrate	Sulphate	Boron	Manganese	Phosphorus (total)	Zinc
	NTU	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l
Samples over PCV	120	159	0	49	32	96	59
Samples with under PCV	206	142	301	252	289	219	247
Samples with no trace	0	0	0	0	0	0	0
Total Samples Taken	**326**	**301**	**301**	**301**	**321**	**315**	**306**

Note: Colours denote levels of samples over PCV (Green = None; Amber = Some; Red = High).

Fields and drain outflows

Drain samples were collected from 14 fields across the farm between 2017–2022. To ensure that there were enough samples collected (for adequate datapoints) through the rotation, the number of sampling dates were summed for each field. The fields were either split (allowing for comparisons within field and across seasons) or followed the farm rotation where comparisons could be made across seasons. Therefore, this report considered ten fields as outlined in Table 7.

Table 7. Fields analysed and the number of sampling entries recorded by field

Field	Number of entries	Split field or field rotation
Appletree	47	Split field
Big Lawn	39	Split field
Blacksmith	35	Split field
Hills	5	Split field
Home Lodge	20	Rotation
Long Meadow	14	Rotation
Paddys	19	Rotation
Shrubbery	29	Rotation
Top 59	31	Rotation
West Farm	31	Rotation

The field drains made it possible to sample areas of the fields under various cropping to monitor the effect on water quality. Field maps and their drainage and outflows are shown in various figures in this report. Where possible, field rotations were followed to understand the impact of cropping and cultivations on water quality. A breakdown is presented for each field, or combination of fields. Due to the number of field drain samples collected (number of entries) varying by field (Table 7), results are presented on a percentage of occurrence basis – the number of times that the parameter exceeded PCV. This enabled comparisons both between fields and across rotations.

Additional data, particularly on yield performance – based on results from the marginal land report (ahdb.org.uk/marginal-land) – may help to improve understanding of the underlying field performance and identify where inputs may be more at risk from losses to water.
In 2021, in addition to the water samples being collected, flow rates were also recorded from the field drain outlets. Calculations on field losses of nitrate could be equated to the amount

lost through the field drains and an approximate value derived for the cost of nitrogen being leached to the drains. Due to the drain flows being captured at spot times through the season, rather than as a continuous flow, the calculations are approximate, as flow rates will vary in relation to the intensity and duration of rainfall. An approximate economic loss was calculated from the nitrate loss per day (kg/day of NO_{-3}) based on ammonium nitrate fertiliser prices of £1.00/kg N, £1.50/kg N or £2.00/kg N.

Appletree and Blacksmiths fields

Up until the autumn of 2020, the rotation and crop establishment approach were the same across each field (Table 8).

Table 8. Crop rotation for Appletree and Blacksmith (2017-2022).

Field	2017	2018	2019	2020*	2021	2022
Appletree	2WW	SBns (CC)	1WW	SBly (CC)	G1	G2
Blacksmith	2WW	SBns (CC)	1WW	SBly (CC)	G1	G2

*Denotes when field splits occurred.

In autumn 2020, the fields were split as follows (shown in Figure 5):

- Appletree: Plough + Cover crop
- Appletree: Overwinter plough
- Blacksmith: Stubble
- Blacksmith: Stubble + Cover crop

From 2020 onwards, the field splits could be monitored to understand the impact of the cover crop on water quality (compared to conventional management) with drain water samples collected from the sampling locations on the map (Figure 5).

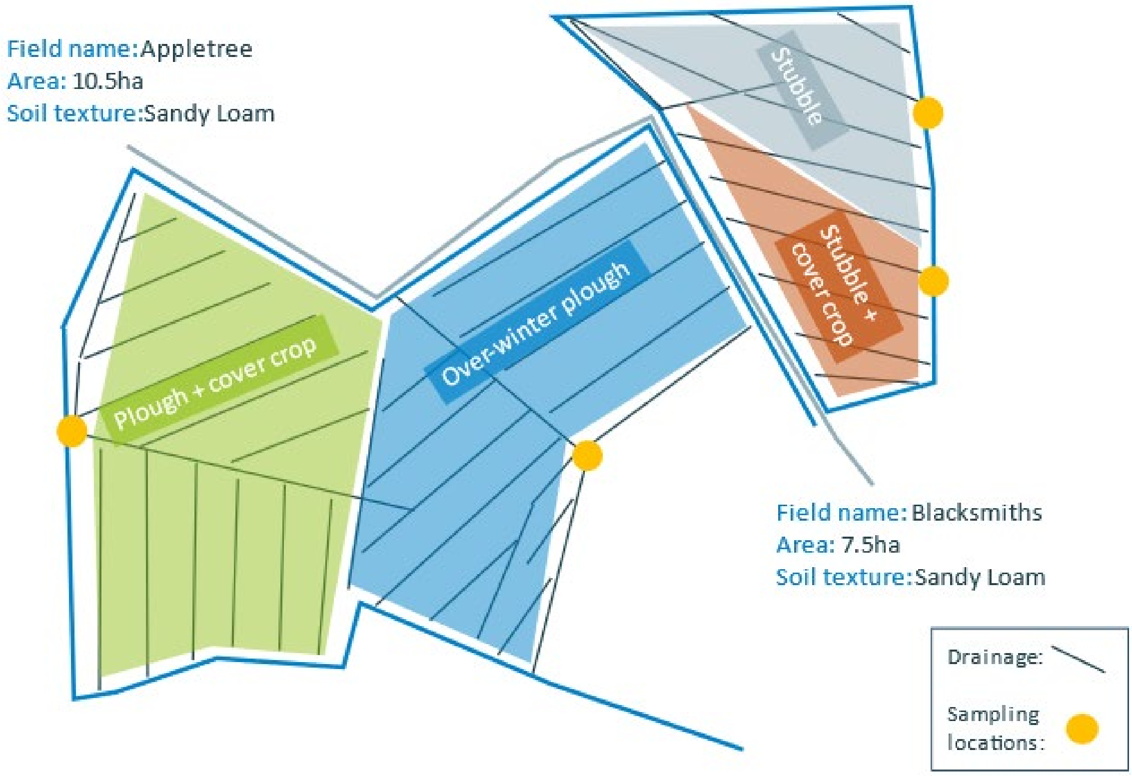


Figure 5. Appletree and Blacksmiths fields with drain layout, field split and sampling location

Daily rainfall from October to March (inclusive) and drainage water nitrate concentrations are shown in Figure 6 (between October 2017 and March 2022). In Appletree, prior to spring beans planting in spring 2018, a cover crop (mustard and oats) was established in the autumn of 2017. Nitrate concentrations were well below the PCV of 50 mg/l during the cover crop and following sowing of the spring beans on 23/03/2018. A spike in nitrate following the sowing of the winter wheat on 29/09/2019 can be seen with nitrate concentration reaching 160 mg/l on 07/12/2019 and is likely because of nitrogen mineralisation following cultivation and the winter rainfall when fields are at or beyond field capacity.

The use of cover crops ahead of the spring barley helped substantially to reduce nitrate concentrations over the winter period to levels lower than 10 mg/l by the end of the winter period, this was substantially lower than the areas either ploughed over-winter or left as stubble. Following the spring barley when herbage grass was undersown, nitrate levels reduced in all but Blacksmith CC, where there was a large spike that gradually reduced over the winter period. It is not clear why there was a large spike in this treatment, but it is possible that with the preceding cover crop substantially reducing nitrates that were captured by the cover crop. Upon destruction the cover crop it is possible that these released much of this nitrogen that had already been lost earlier in the other treatments.

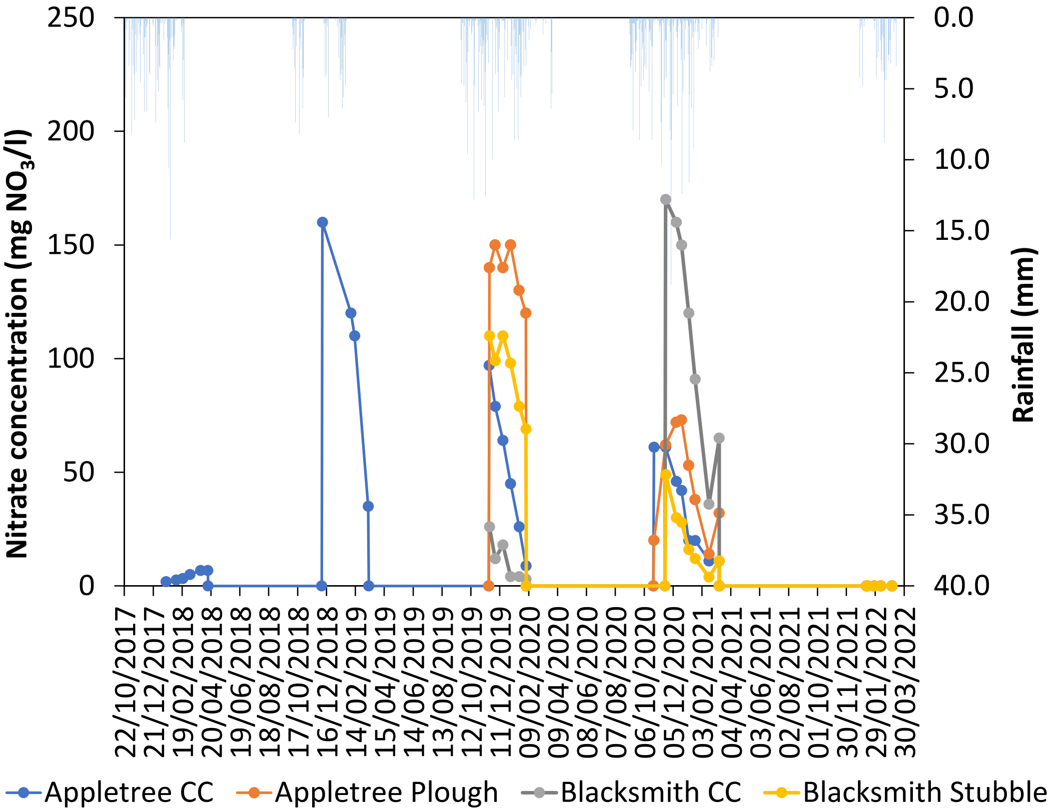


Figure 6. Drainage water nitrate concentrations (mg NO_3/l) and daily rainfall between 22/10/2017 and 30/03/2022 in Appletree and Blacksmith

A full breakdown, by rotation, of the parameters where drain water concentrations exceeded PCV is shown in Table 9. Nitrate levels were greatest in when the field was ploughed over-winter or ploughed, with samples exceeding the PCV in 100% of the occurrences. Levels of nitrates substantially reduced either in CC or grass rotations. Other parameters tended to show higher occurrences during the first year of grass, may be due to low levels of soil cover and less rooting to protect the soil particles from dispersing into the water during winter rainfall. Lowest levels of parameters exceeding PCV were during the second year of grass.

Table 9. Percentage of occurrences where drain water concentrations exceeded PCV in Appletree and Blacksmith fields

Field treatment (rotation, cultivation)	Nitrate	Suspended solids	Boron	Manganese	Metaldehyde	Phosphorus (total)	MCPA	Penta - chlorophenol	Propyzamide	Triclopyr	zinc
Appletree CC CC, ST	0	33	0	0	-	33	0	0	0	0	33
Appletree CC 1WW, MT	75	25	0	0	-	50	0	0	0	0	50
Appletree CC CC, PL	50	17	0	0	-	0	0	0	0	0	0
Appletree CC 1yr Grass, DD	25	25	0	13	-	13	38	13	13	13	38
Appletree CC 2yr Grass, after DD	25	0	0	0	-	0	0	0	0	0	0
Appletree Plough Plough over-winter	100	43	0	0	-	0	0	0	0	0	0
Appletree Plough 1yr Grass, DD	50	38	50	38	-	13	50	13	13	13	63
Appletree Plough 2yr Grass, after DD	0	50	0	0	-	0	0	0	0	0	0
Blacksmith CC CC, ST	0	0	0	0	-	0	0	0	0	0	0
Blacksmith CC 1yr Grass, DD	88	38	38	38	-	0	63	13	25	13	38
Blacksmith CC 2yr Grass, after DD	0	0	0	0	-	0	0	0	0	0	0
Blacksmith Stubble Stubble over-winter	100	33	0	0	-	0	0	0	0	0	0
Blacksmith Stubble 1yr Grass, DD	0	57	43	29	-	14	71	14	43	14	29
Blacksmith Stubble 2yr Grass, after DD	0	0	0	0	-	0	0	0	0	0	0

Big Lawn and Hills fields

Up until the autumn of 2018 the rotation and crop establishment approach were the same across each field (Table 10).

Table 10. Crop rotation for Big Lawn and Hills (2017–2022).

Field	2017	2018	2019*	2020	2021	2022
Big Lawn	1WW	2WW	SLin (CC)	1WW	SBly (CC)	G1
Hills	1WW	2WW	SLin (CC)	1WW	SBly (CC)	G1

*Denotes when field splits occurred.

From autumn 2018, the fields were split as follows (shown in Figure 7):

- Big Lawn: Plough + Cover crop
- Big Lawn: Overwinter plough
- Hills: Stubble
- Hills: Stubble + Cover crop

From 2018 onwards the field splits could be monitored to understand the impact of the cover crop on water quality compared to conventional management with drain water samples collected from the sampling locations on the map (Figure 7).

Daily rainfall from October to March (inclusive) and drainage water nitrate concentrations are shown in the Figure 4 between November 2017 and March 2022. Water samples were collected across the five-year period in Big Lawn CC area. In 2018, when Big Lawn was drilled with second winter wheat, nitrate concentrations fluctuated but were generally above the 50 mg/l PCV. A cover crop was sown as a split in each field (see Figure 3) on 10/09/2018 following the second wheat either after ploughing (Big Lawn) or directly into stubble (Hills) as that allowed for a comparison between plough + cover crop cf. overwinter plough or stubble + cover crop cf. stubble. During the autumn/winter of 2018/19, where the cover crop had established, nitrate concentrations were below 50 mg/l compared to between 2 to 6 times higher in the stubble or over winter plough treatments.

Big lawn continued to be monitored following the cover crop in 2020 (first winter wheat); 2021/22 (spring barley under-sown with herbage grass). In both winter wheat and spring barley, nitrate concentrations exceeded 50 mg/l in both the autumn/winter 2019/20 and 20202/21. During the autumn/winter of 2021/22, the nitrate concentrations remained at 20–23 mg/l, well below the PCV of 50 mg/l.

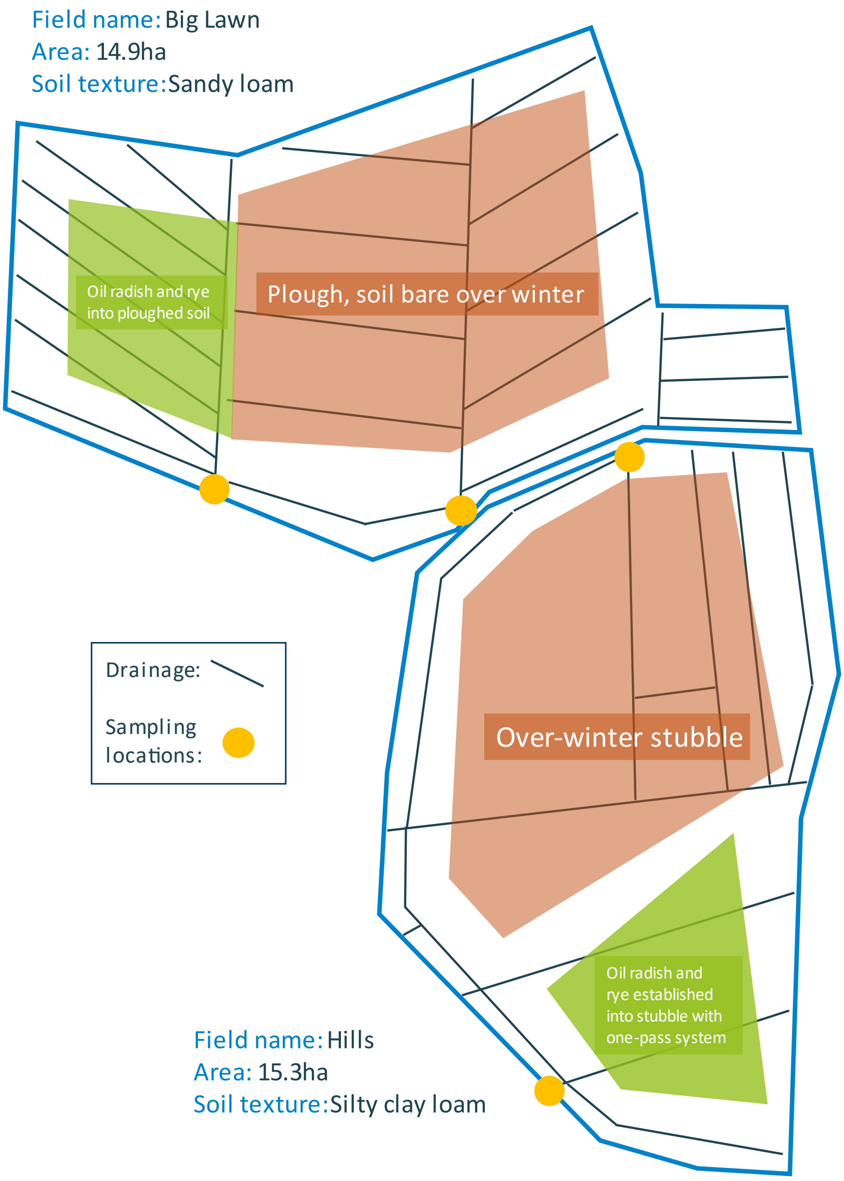


Figure 7. Big Lawn and Hills fields with drain layout, field split and sampling location

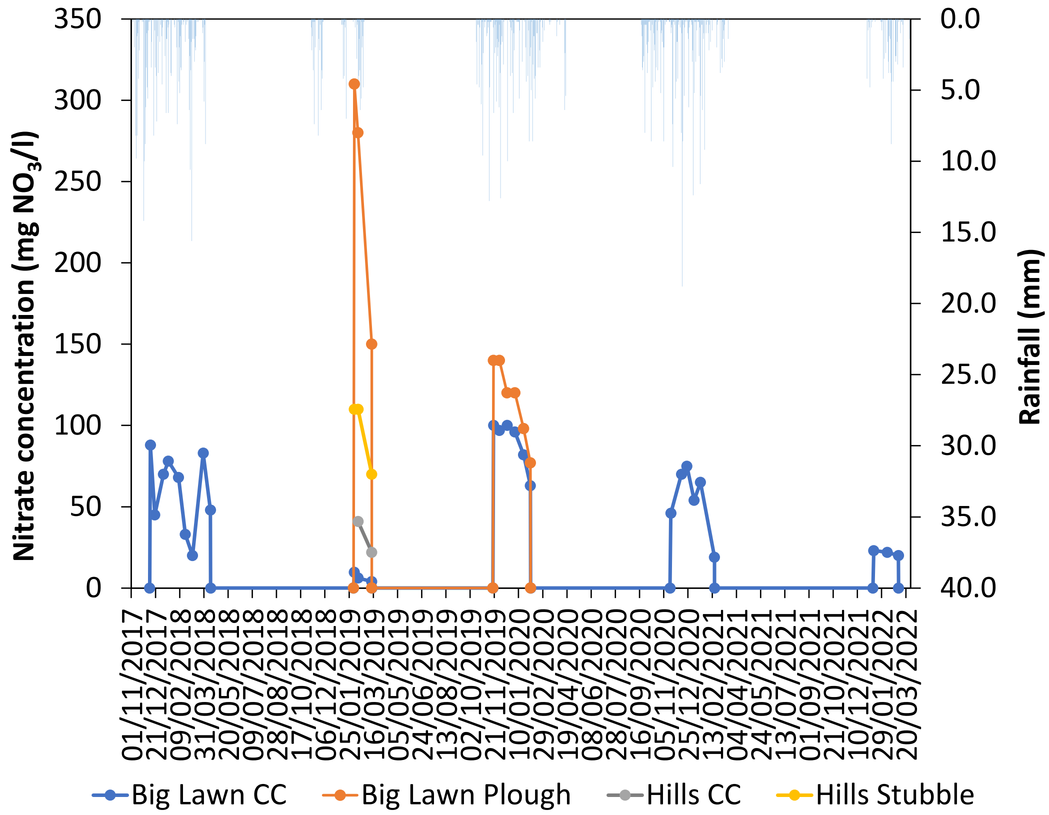


Figure 8. Drainage water nitrate concentrations (mg NO_3/l) and daily rainfall between 01/11/2017 and 20/03/2022 in Big Lawn and Hills fields

The value of cover crops and herbage grass have been valuable in reducing the nitrate concentrations in the water across the rotation. However, cropping with winter wheat and spring barley resulted in nitrate peaks above the PCV of 50mg/l and highlights the risk from nitrate losses during periods of high rainfall.

A full breakdown, by rotation, of the parameters where drain water concentrations exceeded PCV is shown in Table 11. Nitrate levels exceeded the PCV in 100% of occurrences where the field was over-winter stubble or over-winter plough. In contrast, cover crops reduced nitrate losses over 50 mg/l in all cases. Other parameters tended to show lower occurrences apart from phosphorous and zinc, which tended to remain higher throughout the rotation. A spike in losses were seen in the cover crop after first winter wheat and this may have been because of poorer soil cover and rooting during the autumn period increasing the risk of leaching to water during this period.

Table 11. Percentage of occurrences where drain water concentrations exceeded PCV in Big Lawn and Hills fields

Field treatment (rotation, cultivation)	Nitrate	Suspended solids	Boron	Manganese	Metaldehyde	Phosphorus (total)	MCPA	Penta - chlorophenol	Propyzamide	Triclopyr	zinc
Hills Stubble Over winter stubble	100	0	0	0	-	33	0	-	0	-	33
Hills CC CC, Min till	0	50	0	0	-	50	0	-	0	-	50
Big Lawn Plough Over winter plough	100	33	0	0	-	33	0	-	0	-	33
Big Lawn Plough 1WW, Strip till	100	33	0	0	-	17	0	-	0	-	33
Big Lawn CC 2WW, Strip till	56	56	0	0	-	67	0	-	0	-	44
Big Lawn CC CC, Plough	0	33	0	0	-	67	0	-	0	-	33
Big Lawn CC 1WW, Strip till	86	14	0	0	-	0	0	-	0	-	14
Big Lawn CC CC, Strip till	71	43	57	43	-	14	14	-	14	-	43
Big Lawn CC 1Yr Grass, Direct Drill	0	33	0	0	-	0	0	-	0	-	0

Home Lodge field

The field followed the rotation in Table 12. In 2020 the winter oilseed rape failed and was re-drilled with spring linseed. Drain water samples were collected from the sampling locations on the map (Figure 9).

Table 12. Crop rotation for Home Lodge (2017–2022)

Field	2017	2018	2019	2020	2021	2022
Home Lodge	SBns (CC)	1WW	Wbly	WOSR (failed) SLin	1WW	2WW

Daily rainfall from December to March (inclusive) and drainage water nitrate concentrations are shown in the Figure 6 between December 2017 and March 2022. Water samples were collected across the four-year period (from 2019 to 2022), no water samples were collected in 2017 or 2018.

In 2019, when Home Lodge was drilled with winter barley, nitrate concentrations were a little above the 50 mg/l PCV across the January to March period. After the failed oilseed rape, a peak in nitrate concentration (99 mg/l) resulted from the mineralisation of soil N. The mineralisable N is likely to have leached from the soil due to the low level of root biomass. In September 2020, first winter wheat was sown and resulted in nitrate concentrations above the PCV. However, in February 2021, this had reduced to 51 mg/l and further declined to 21 mg/l in March 2021. The second winter wheat sown in October 2021 resulted in nitrate concentrations of 59 to 66 mg/l between January and March 2022.

A full breakdown, by rotation, of the parameters where drain water concentrations exceeded PCV is shown in Table 13. Nitrate levels exceeded the PCV in 50 to 100% of occurrences across the rotation. Other parameters tended to show lower occurrences apart from the first winter wheat where nitrate, suspended solids and boron generally exceeded 50% of occurrences.

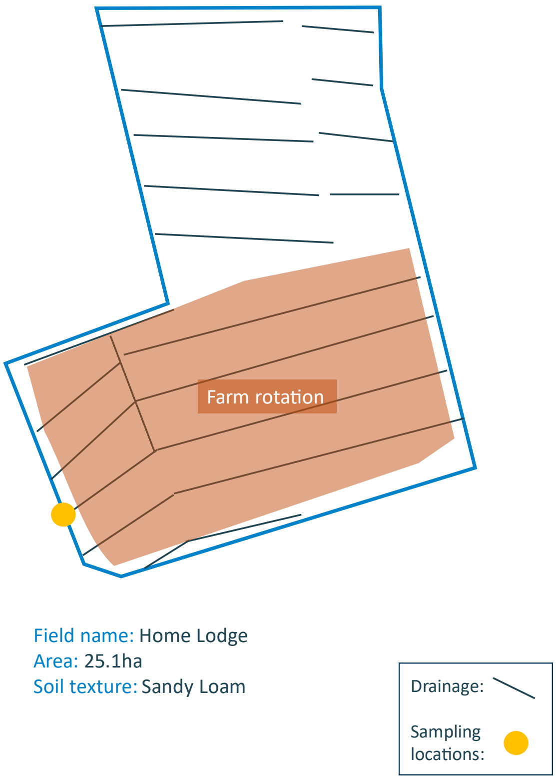


Figure 9. Home Lodge field with drain layout, field rotation and sampling location

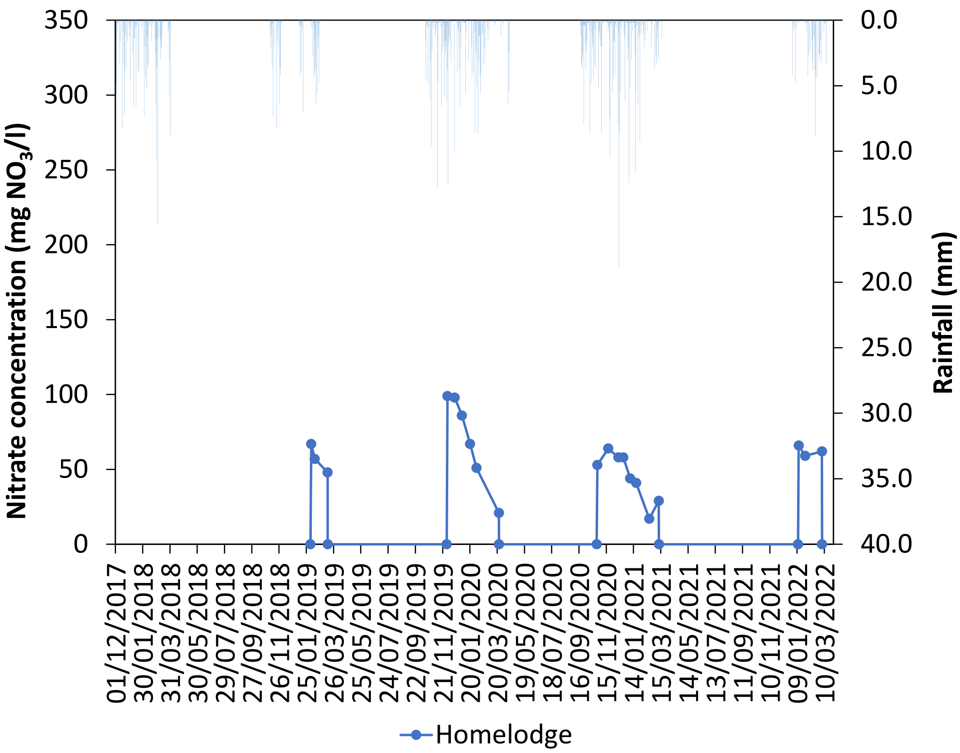


Figure 10. Drainage water nitrate concentrations (mg NO_3/l) and daily rainfall between 01/12/2017 and 10/03/2022 in Home Lodge field

Table 13. Percentage of occurrences where drain water concentrations exceeded PCV in Home Lodge

Field treatment (rotation, cultivation)	Nitrate	Suspended solids	Boron	Manganese	Metaldehyde	Phosphorus (total)	MCPA	Penta - chlorophenol	Propyzamide	Triclopyr	zinc
Home Lodge Hybrid barley, Plough	67	0	0	0	-	33	-	0	0	0	0
Home Lodge Linseed, Strip till	83	33	0	0	-	0	-	0	0	0	0
Home Lodge 1WW, Direct Drill	50	50	50	25	-	0	-	13	13	13	38
Home Lodge 2WW, Plough	100	0	0	0	-	0	-	0	0	0	0

Paddy's and Long Meadow fields

The rotation in Paddy's and Long Meadow is shown in Table 14. Water samples were collected from Paddy's during the period from January 2018 to March 2021. In Long Meadow, water samples were collected from November 2020 to March 2021. In Long Meadow, cover crops were established ahead of the spring linseed in 2019. In Paddy's cover crops were established ahead of the spring cropping in 2017, 2018 and 2021.

Table 14. Crop rotation for Paddy's and Long Meadow (2017–2022)

Field Name	2017	2018	2019	2020	2021	2022
Long Meadow	1WW	2WW	SLin (CC)	1WW	SBns	1WW
Paddy's	SBly (CC)	SLin (CC)	1WW	2WW	SBly (CC)	1WW

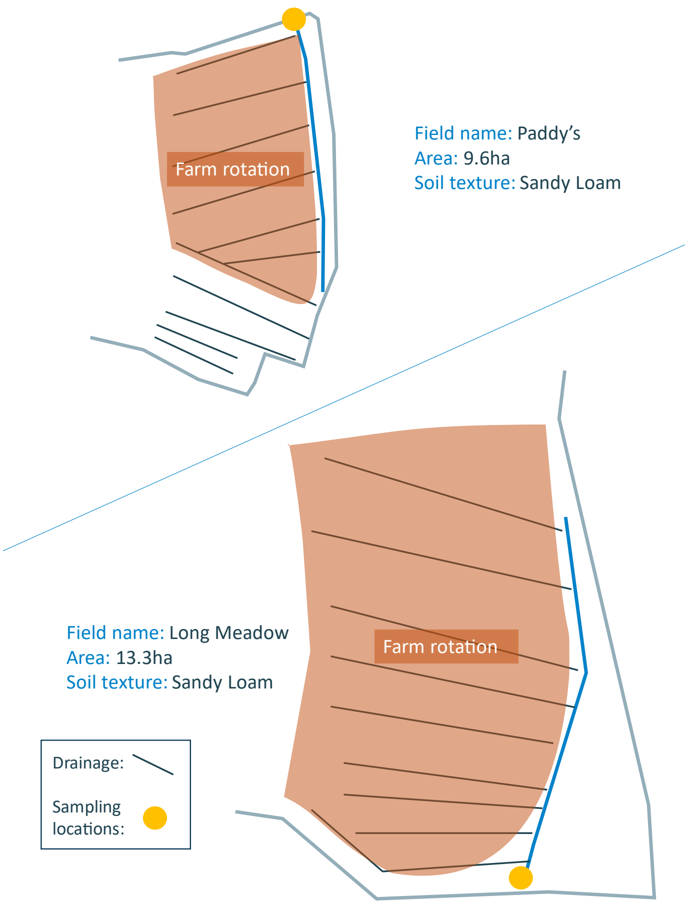


Figure 11. Paddy's and Long Meadow fields with drain layout, field rotation and sampling location

Daily rainfall from December to March (inclusive) and drainage water nitrate concentrations are shown in the Figure 12 for Long Meadow between December 2017 and March 2022. Water samples were collected across the three-year period from 2019 to 2021. Nitrate concentrations were all above the 50 mg/l for both winter periods (11/2020 to 03/2020 and 11/2021) when the drains were running. The highest nitrate concentrations occurred during autumn 2020 when levels peaked at 170 mg/l. This is likely due to mineralisation following cultivation and establishment of the winter wheat.

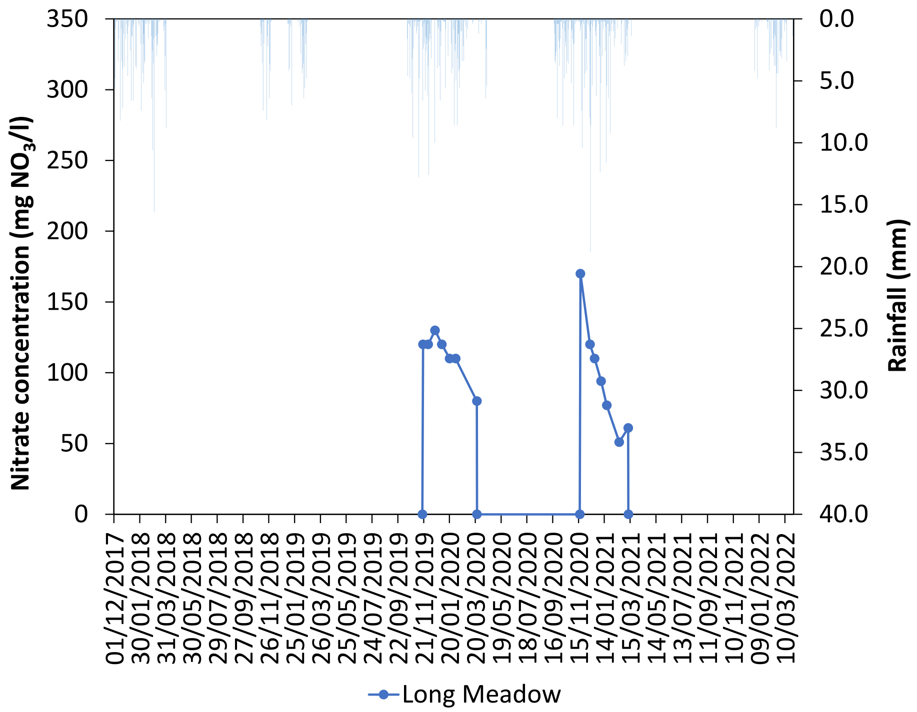


Figure 12**.** Drainage water nitrate concentrations (mg NO_3/l) and daily rainfall between 01/12/2017 and 10/03/2022 in Long Meadow

Daily rainfall from December to March (inclusive) and drainage water nitrate concentrations are shown in the Figure 13 for Paddy’s between December 2017 and March 2022. Water samples were collected across the four-year period from 2018 to 2021. Nitrate concentrations were all above the 50 mg/l in both winter periods (12/2017 to 03/2018 and 11/2018 to 03/2019) when the drains were running. The highest nitrate concentrations occurred during November 2018 when levels peaked at 160 mg/l. This is likely due to mineralisation following cultivation and establishment of the winter wheat. During autumn 2020, a cover crop was established ahead of the spring barley; nitrate levels were all below 15 mg/l suggesting the benefit a well-established cover crop can be at minimising nitrate losses to water.

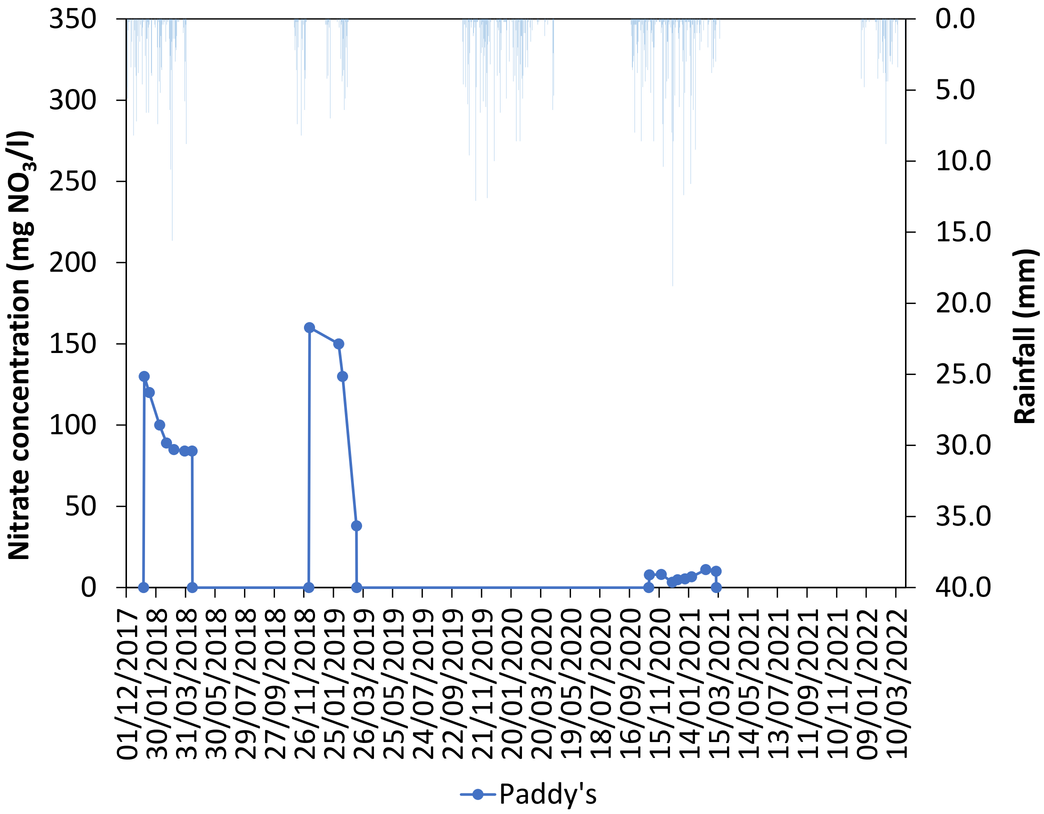


Figure 13. Drainage water nitrate concentrations (mg NO_3/l) and daily rainfall between 01/12/2017 and 10/03/2022 in Paddy’s

A full breakdown, by rotation, of the parameters where drain water concentrations exceeded PCV is shown in Table 15. Nitrate levels exceeded the PCV in 75 to 100% of occurrences across the over-wintered stubble/plough and the first winter wheat. Other parameters tended to be higher in the over-wintered stubble compared to the 1WW and this could be due to the lack of soil cover protecting the soil from rainfall impact allowing sediment and nutrient to be carried into the drains. The cover crop in Paddy’s field substantially reduced nitrate concentrations to below PCV through the winter period. However, other parameters tested tended to increase, although it is not clear why this occurred.

Table 15. Percentage of occurrences where drain water concentrations exceeded PCV in Long Meadow and Paddy’s

Field treatment (rotation, cultivation)	Nitrate	Suspended solids	Boron	Manganese	Metaldehyde	Phosphorus (total)	MCPA	Penta - chlorophenol	Propyzamide	Triclopyr	zinc
Long Meadow 1WW, Strip till	100	0	0	0	-	100	-	0	0	0	0
Long Meadow Overwinter Stubble	100	14	14	43	-	100	-	14	14	14	14
Paddy's Over winter plough	100	0	0	0	-	14	-	0	0	0	14
Paddy's 1WW, Strip till	75	0	0	0	-	50	-	0	0	0	0
Paddy's CC, Strip till	0	25	38	25	-	25	-	13	13	13	13

Shrubbery and West Farm

The rotation in Shrubbery and West Farm is shown in Table 16. Water samples were collected from Shrubbery and West Farm during the period from December 2017 to March 2022. No cover crops were established in Shrubbery during the rotation.

Table 16. Crop rotation for Shrubbery and West Farm (2017–2022)

Field	2017	2018	2019	2020	2021	2022
Shrubbery	G1	G2	1WW	2WW	WOSR	1WW
West Farm	1WW	2WW	Fallow (CC)	SLin	1WW	WOSR

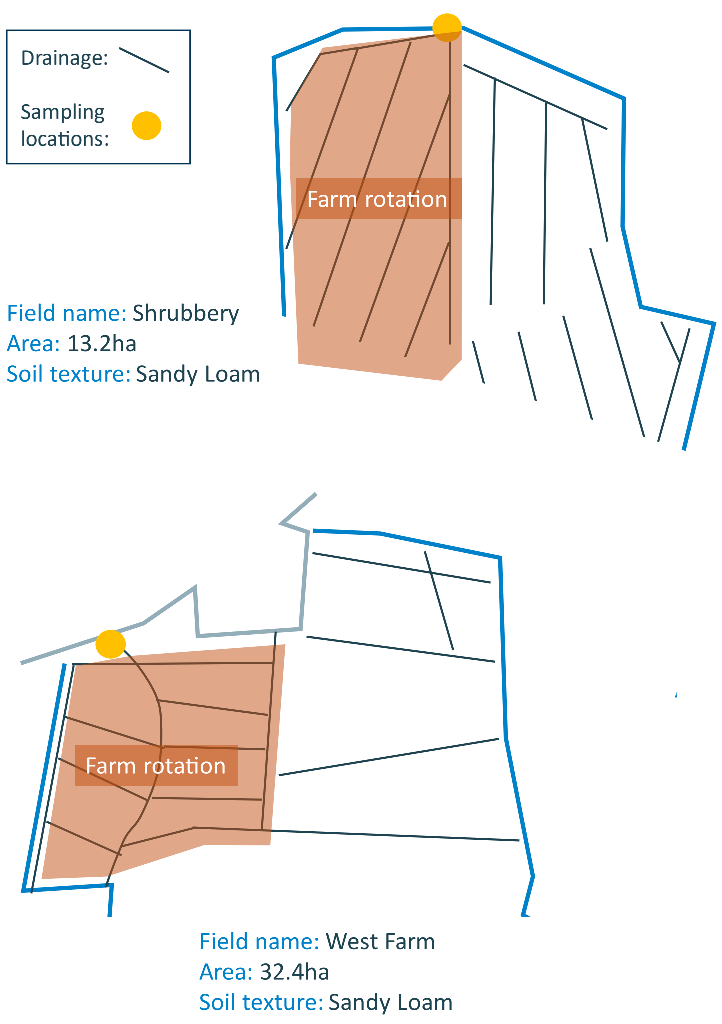


Figure 14. Shrubbery and West Farm fields with drain layout, field rotation and sampling location

Daily rainfall from December to March (inclusive) and drainage water nitrate concentrations are shown in the Figure 15 for Shrubbery between December 2017 and March 2022. Water samples were collected across the five-year period from 2018 to 2022. Nitrate concentrations the 2nd-year of grass resulted in low levels of nitrate concentrations (all below 50 mg/l). However, in the subsequent seasons (all winter cropping), nitrates all peaked above 50 mg/l and in autumn 2018 (first winter wheat) nitrate concentrations peaked at 190 mg/l and remained above 50 mg/l for the winter period. This was also the case for the second cereal in 2020 and first wheat in 2022. The nitrate concentration in the oilseed rape crop (sown in August 2020) peaked at 110 mg/l in October 2020 but declined to 20 mg/l in December 2020. This potentially shows that oilseed rape has potential to scavenge the nitrogen in the soil and reduce losses to water.

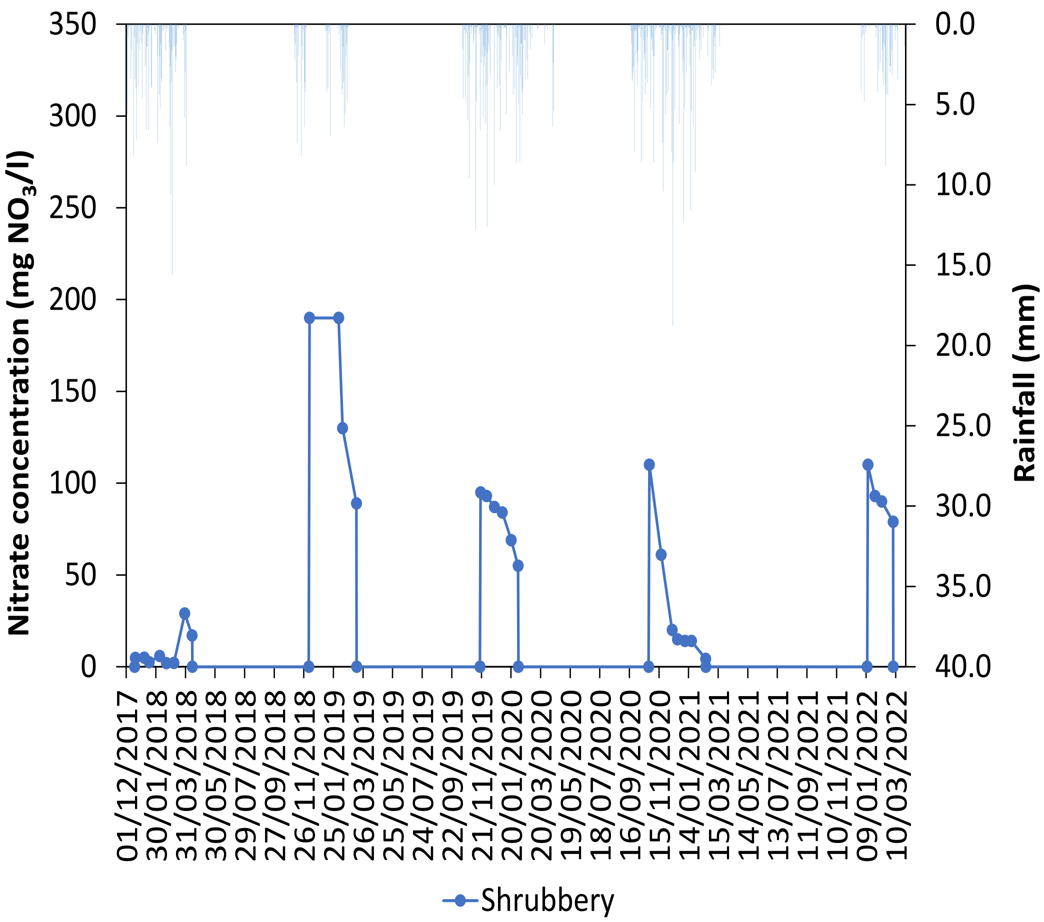


Figure 15. Drainage water nitrate concentrations (mg NO_3/l) and daily rainfall between 01/12/2017 and 10/03/2022 in Shrubbery

Daily rainfall from December to March (inclusive) and drainage water nitrate concentrations are shown in the Figure 16 for West Farm between December 2017 and March 2022. Nitrate concentrations in the second wheat resulted in fluctuating levels between 17 and 92 mg/l. The following autumn (September 2018) a cover crop was established resulting in nitrate concentrations remaining below 10 mg/l. High nitrate concentrations peaked at 230–250 mg/l and remined ostensibly high in both the spring linseed (2020) and first winter wheat (2021) seasons. Again, like in Shrubbery, when oilseed rape was established (August 2021) nitrate concentrations were below 50 mg/l through the winter period.

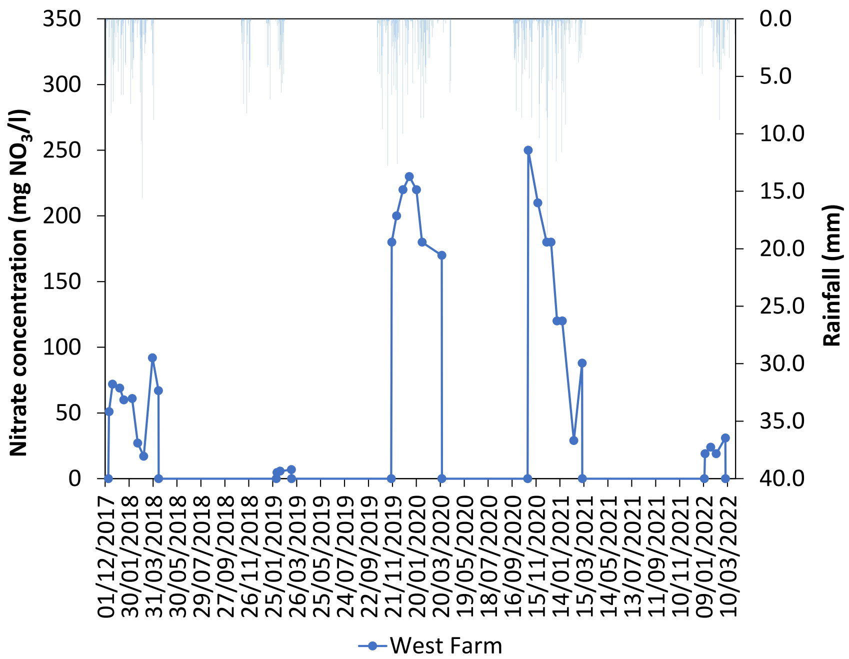


Figure 16. Drainage water nitrate concentrations (mg NO_3/l) and daily rainfall between 01/12/2017 and 10/03/2022 in West Farm

A full breakdown, by rotation, of the parameters where drain water concentrations exceeded PCV is shown in Table 17. Nitrate levels exceeded the PCV in 75 to 100% of occurrences in first and second winter wheat cropping. Nitrate concentrations were substantially reduced, with no occurrences exceeding the PCV when in cover crop or grass. The percentage of occurrences of nitrate concentrations exceed PCV were also reduced in oilseed rape crops. Other parameters, such a propyzamide, applied in oilseed rape, was greater (57% occurrences) when oilseed rape was established as the single crop. Where oilseed rape was sown with a companion crop, propyzamide occurrences over the PCV reduced to 13%.

Table 17. Percentage of occurrences where drain water concentrations exceeded PCV in West Farm

Field treatment (rotation, cultivation)	Nitrate	Suspended solids	Boron	Manganese	Metaldehyde	Phosphorus (total)	MCPA	Penta - chlorophenol	Propyzamide	Triclopyr	zinc
Shrubbery 2nd year grass, plough	0	25	0	0	-	25	-	-	0	-	13
Shrubbery 1WW, Min Till	100	0	0	0	-	25	-	-	0	-	0
Shrubbery 2WW, Min Till	100	33	0	0	-	0	-	-	0	-	0
Shrubbery WOSR, Strip Till	29	43	71	14	-	0	-	-	57	-	14
Shrubbery 1WW, Min till	100	0	0	0	-	0	-	-	0	-	0
West Farm 2WW, Strip till	78	33	0	0	11	33	-	0	0	0	33
West Farm CC, Strip till	0	67	0	0	0	67	-	0	0	0	33
West Farm Linseed, Min till	100	43	0	0	0	0	-	0	0	0	14
West Farm 1WW, Direct Drill	88	63	50	38	0	13	-	13	13	13	63
West Farm OSR + Companion crop, Strip till	0	0	0	0	0	0	-	0	0	0	0

Top 59

The rotation in Top 59 is shown in Table 18. A catch crop was sown in late August 2022 before second winter wheat in late October 2022. Water samples were collected from Top 59 during the period from December 2017 to March 2022.

Table 18. Crop rotation for Top 59 (2017–2022)

Field	2017	2018	2019	2020	2021	2022
Top 59	2WW	Wbar	G1	G2	1WW	2WW (CC)

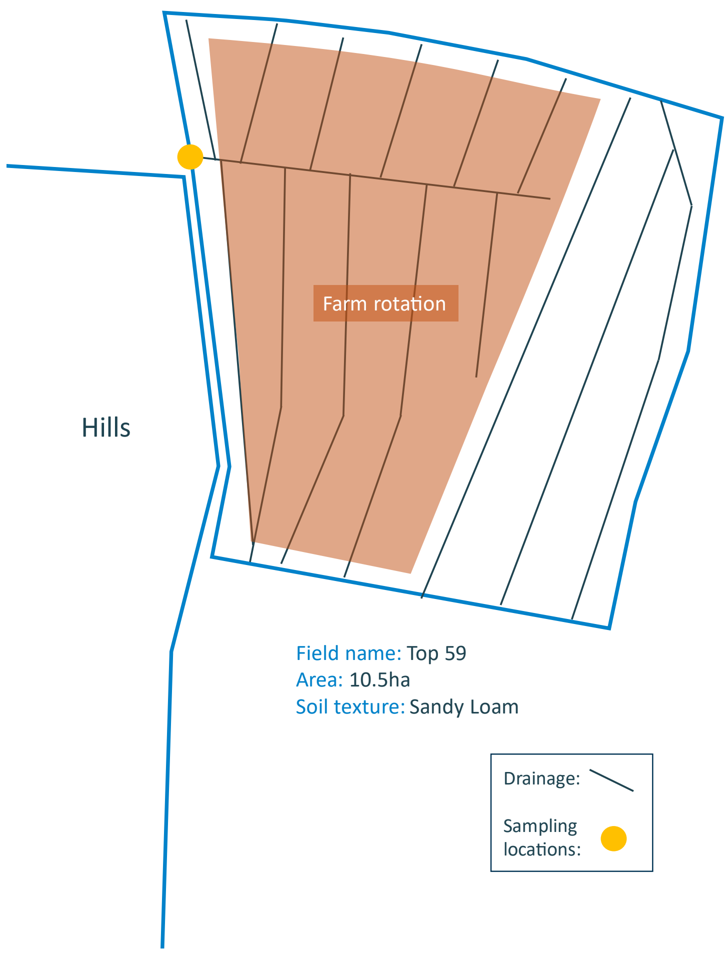


Figure 17. Top 59 fields with drain layout, field rotation and sampling location

Daily rainfall from December to March (inclusive) and drainage water nitrate concentrations are shown in the Figure 18 for Top 59 between December 2017 and March 2022. Nitrate concentrations in the winter barley (2018) was variable, but in general remained below 50 mg/l. In September 2018, grass was established and nitrate concentrations peaked at 140 mg/l and remained above 50 mg/l over the winter period. The second year of grass (2020) resulted in very low nitrate concentrations, below 40 mg/l. The subsequent establishment of first winter wheat (October 2020) resulted in a very high peak in nitrate of 300 mg/l before declining sharply, but still exceeding 50 mg/l in most instances. The use of a catch crop ahead of the second wheat substantially reduced nitrate concentrations to below 20 mg/l.

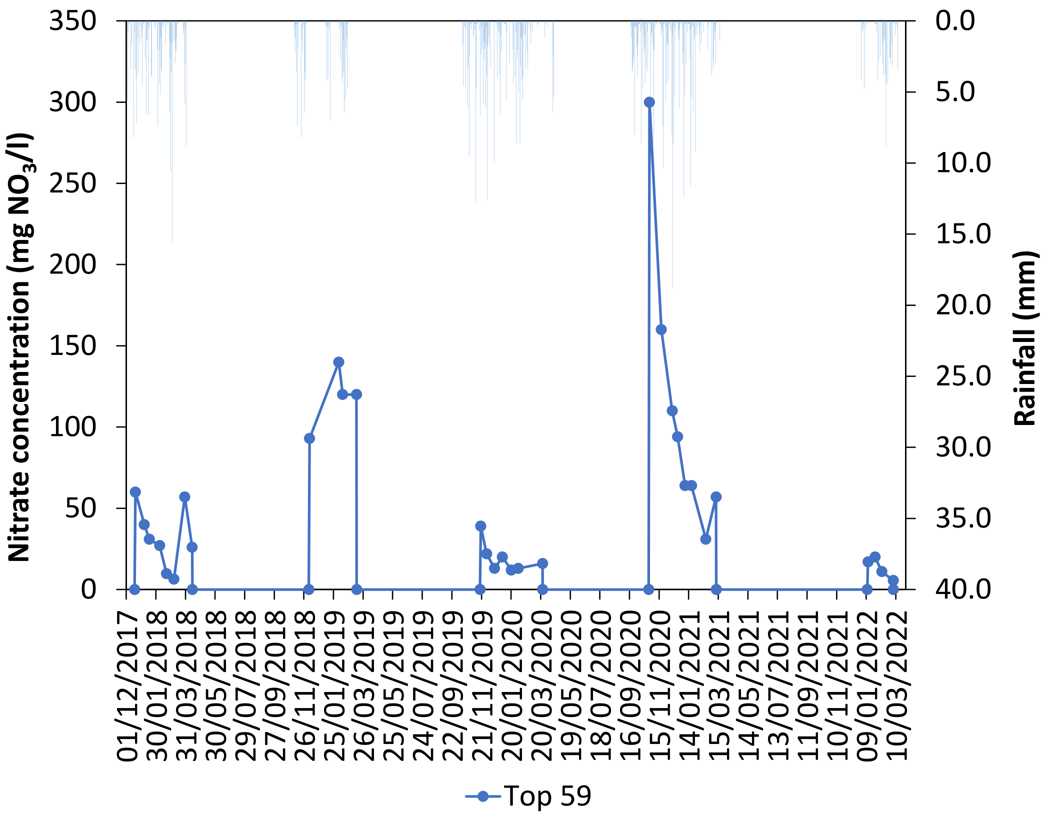


Figure 18. Drainage water nitrate concentrations (mg NO_3/l) and daily rainfall between 01/12/2017 and 10/03/2022 in Top 59

A full breakdown, by rotation, of the parameters where drain water concentrations exceeded PCV is shown in Table 19. Nitrate levels exceeded the PCV in 75 to 100 percent of occurrences in first winter wheat and first year of grass. Ploughing after grass, increased the occurrences of concentrations in the water compared to lower disturbance approaches.

Table 19. Percentage of occurrences where drain water concentrations exceeded PCV in Top 59

Field treatment (rotation, cultivation)	Nitrate	Suspended solids	Boron	Manganese	Metaldehyde	Phosphorus (total)	MCPA	Penta - chlorophenol	Propyzamide	Triclopyr	zinc
Top 59 Winter Barley, Plough	25	38	0	0	-	25	-	0	0	0	25
Top 59 1Yr Grass, DD	100	75	0	0	-	50	-	0	0	0	75
Top 59 2nd Yr Grass, after DD	0	50	0	0	-	33	-	0	0	0	17
Top 59 1WW, Plough	88	63	88	63	-	25	-	13	13	13	75
Top 59 2WW, Strip till after catch crop	0	0	0	0	-	0	-	0	0	0	0

Cost analysis on nitrate losses

In 2021, it was possible to calculate approximate nitrate losses to drains, based on nitrate concentrations and flow rates. Calculations on field losses of nitrate could be equated to the amount lost through the field drains and an approximate value derived for the cost of N being leached to the drains. Due to the drain flows being captured at spot times through the season, rather than as a continuous flow, the calculations are approximate, as flow rates will vary in relation to the intensity and duration of rainfall.

The approximate nitrate losses (kg/day) are shown in Table 20 for fields in a range of cropping scenarios. Losses were calculated for each field as mean, max and min during the period (October 2020–March 2021). Average losses ranged from 0.09 to 1.83 kg/day, with a daily maximum up to 4.80 kg/day. The highest losses were typically, but not in all instances, associated with first winter wheat. In general, cover cropping and grass were associated with the lowest losses of nitrates, typically below 0.46 kg/day.

The associated cost of nitrate losses was calculated based on the cost of ammonium nitrate (AN) fertiliser; £1.00 kg N, £1.50 kg N or £2.00 kg N. Mean cost of nitrate losses across all fields was £1.67 per day (at £2.00 kg N) and ranged from £0.19/da to £3.67/day. The cost reflects the nitrate losses, therefore the fields associated with the greatest losses were also where the greatest financial losses occurred. As an example, the cost of nitrate losses in a cover crop (Paddy's) was £0.18/ day compared to a first winter wheat (West Farm) where the cost was £3.67/day. This is a twenty-fold increase when comparing a first winter wheat to a cover crop.

Table 20. Approximate nitrate loss to drain water per day and the economic cost based on ammonium nitrate (AN) fertiliser

Field (rotation)	Approximate nitrate loss (kg/day)			Nitrate £/day (AN cost @ £1.00/kg N)			Nitrate £/day (AN cost @ £1.50/kg N)			Nitrate £/day (AN cost @ cost £2.00/kg N)		
	Average	Max	Min	Average	Max	Min	Average	Max	Min	Average	Max	Min
Appletree (CC fb Grass)	0.46	1.76	0.01	0.46	1.76	0.01	0.69	2.64	0.01	0.92	3.51	0.01
Appletree (Plough fb Grass)	0.41	0.94	0.02	0.41	0.94	0.02	0.61	1.41	0.03	0.81	1.88	0.04
Big Lawn (CC fb Sbly)	1.49	3.74	0.65	1.49	3.74	0.65	2.24	5.62	0.97	2.99	7.49	1.30
Blacksmith (CC fb Grass)	1.13	2.45	0.02	1.13	2.45	0.02	1.69	3.67	0.03	2.25	4.90	0.04
Blacksmith (Stubble fb Grass)	0.09	0.15	0.00	0.09	0.15	0.00	0.14	0.22	0.00	0.19	0.29	0.00
Home Lodge (1WW)	0.68	1.25	0.03	0.68	1.25	0.03	1.02	1.88	0.04	1.36	2.51	0.06
Long Meadow (Stubble fb Sbns)	1.27	3.33	0.06	1.27	3.33	0.06	1.90	4.99	0.09	2.54	6.65	0.12
Paddy's (CC)	0.09	0.38	0.00	0.09	0.38	0.00	0.13	0.57	0.01	0.18	0.76	0.01
Shrubbery (WOSR)	0.48	1.90	0.09	0.48	1.90	0.09	0.72	2.85	0.13	0.96	3.80	0.18
Top 59 (1WW)	1.26	3.69	0.06	1.26	3.69	0.06	1.90	5.53	0.09	2.53	7.37	0.12
West Farm (1WW)	1.83	4.80	0.03	1.83	4.80	0.03	2.75	7.20	0.04	3.67	9.60	0.06
MEAN	**0.84**	**2.22**	**0.09**	**0.84**	**2.22**	**0.09**	**1.25**	**3.32**	**0.13**	**1.67**	**4.43**	**0.18**

The impact of rotation and cultivation on water quality

The dynamics of losses of nutrients and pesticides are complicated, driven by management (choice of cropping and tillage intensity) and environmental factors (such as rainfall, temperature) and conditions for crops to establish to allow for improved rooting, soil structure and nutrient uptake to protect the soil cover, thus minimising soil particle loss by direct rainfall impact and dispersion and indirectly by slowing water movement through the soil.

When collating the dataset for the fields and breaking down the fields by rotation (Table 21) the percentage of occurrences where the drain water concentrations exceeded PCV can be seen by crop type. Crops that have the greatest reduction in nitrate concentrations were 1st and 2nd year grass, winter barley (not hybrid barley) and cover crops. However, these can be complicated by the previous cropping, so for example 1st year grass often follows cereals (either winter wheat or spring barley) and, depending on the season and the yield potential of the crop, nitrogen uptake and use efficiency may result in higher levels of post-harvest soil nitrogen being mineralised when the next crop is established. This mineralisable nitrogen may not be sufficiently taken up in some crops during their early establishment phase and risk being lost by leaching.

In general, crops with a larger root system during the autumn, such as. hybrid barley, oilseed rape, cover crops and grass (particularly second year grass), were shown to reduce the percentage of occurrences where drain water concentrations of nitrate exceeded PCV. This contrasts with first winter wheat and over-winter (either stubble or ploughed) treatments, where the percentage of occurrences where drain water nitrate concentrations exceeded PCV were substantially greater. Other parameters tested tended to show that second year grass and hybrid barley were the best crops at reducing the percentage of occurrences where drain water concentrations exceeded PCV.

In terms of cultivation, the percentage of occurrences where drain water concentrations exceeded PCV were reduced substantially, particularly evident for nitrate concentrations, where strip tillage and direct drilling resulted in halving the percentage of occurrences. The absolute percentage of occurrences for reducing nitrates appeared to be lower with ploughing than min till, this is likely to be a result of the sequence of rotation where nitrate mineralisation following the previous crop is greater, irrespective of the following cultivation. However, the clear trend in reduced intensity of tillage associated with lowering the occurrences where nitrate concentrations exceed PCV is shown in Figure 15. Compared to an over wintered stubble or plough, where nitrates exceed the PCV in all occurrences;

moving to direct drilling reduced occurrences by two-thirds. The rank order is not likely to be absolute due to interaction with rotation and rainfall during the autumn/winter period. However, the main trend for lower nitrate occurrence exceeding PCV with a reduction in tillage intensity is the key message.

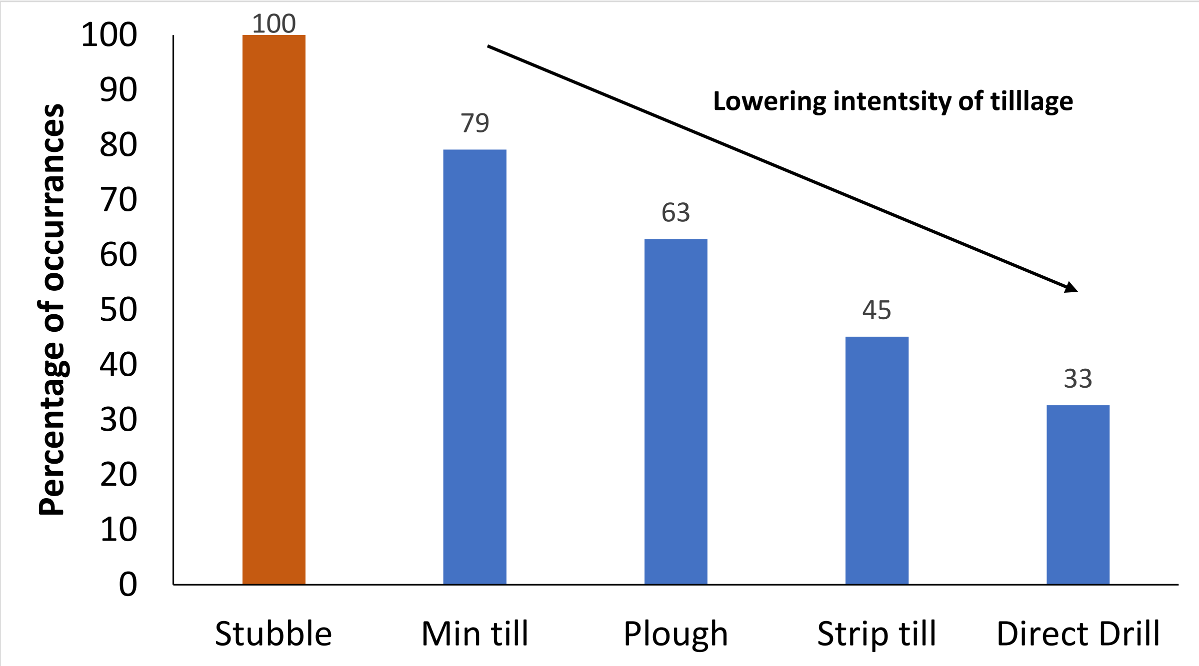


Figure 19. Percentage of occurrences of nitrate losses associated with tillage intensity. Blue bars are all cropping, under differing tillage approaches. The orange bar, denotes an over-wintered stubble or plough.

Table 21. Percentage of occurrences where drain water concentrations exceeded PCV by rotation

Field treatment	Nitrate	Suspended solids	Boron	Manganese	Metaldehyde	Phosphorus (total)	MCPA	Penta - chlorophenol	Propyzamide	Triclopyr	zinc
1WW	81	25	19	14	0	14	4	5	5	5	26
2WW	61	13	0	0	2	7	0	0	0	0	7
1yr Grass	49	49	22	17	0	24	31	7	13	7	41
2yr Grass	0	26	0	0	0	15	0	0	0	0	10
CC	24	29	12	8	0	32	2	2	3	2	22
Hybrid Barley	67	0	0	0	0	33	0	0	0	0	0
Linseed	92	38	0	0	0	0	0	0	0	0	7
OSR	50	21	0	0	0	0	0	0	0	0	0
Over-winter	100	16	3	0	0	25	0	3	3	3	19
Winter Barley	25	38	0	0	0	25	0	0	0	0	25

Table 22. Percentage of occurrences where drain water concentrations exceeded PCV by cultivation

Field treatment	Nitrate	Suspended solids	Boron	Manganese	Metaldehyde	Phosphorus (total)	MCPA	Penta - chlorophenol	Propyzamide	Triclopyr	zinc
Stubble	100	16	5	0	0	25	0	5	5	5	16
Plough	63	25	9	6	0	22	0	1	1	1	19
Min till	79	25	0	0	0	21	0	0	0	0	19
Strip till	45	25	11	5	1	20	1	1	6	1	17
Direct Drill	33	37	18	14	0	10	17	6	9	6	28

Wider research on cover crops and water quality

Wider research on the rotational use of cover crops and their impacts on farming systems is described below (with links to further information).

New Farming Systems (NFS) long-term cover crop study:

The New Farming Systems (NFS) project was set up in 2007 and is on-going with support from the Morley Agricultural Foundation (TMAF) and the JC Mann Trust. The NFS experiment is in Bullswood Field (Morley, Norfolk) on a medium sandy loam soil (Ashley series). Four cultivation techniques and two rotations are employed, resulting in 8 treatments. The experiment has a fully replicated factorial design with four replicates. Each plot is 12m x 36m to facilitate the use of farm scale equipment and techniques and all inputs are consistent with local best practice. Rotations alternate between winter cereals and combinable break crops, and rotations are differentiated further by the presence/absence of an autumn cover crop/companion crop. Cover crops are typically sown in late August/early September and destroyed using glyphosate in the following January/February. Cultivation approaches follow an annual plough inversion tillage approach (*c*. 20-25cm), deep (*c*. 20-25cm) non-inversion tillage or shallow (*c*. 10 cm) non-inversion tillage (typically using tine and disc-based systems) or a managed system (decided on an annual basis). Non-inversion treatments used a Sumo Trio cultivator.

The interaction of the cover crop and primary tillage method on the yield of other crops in the rotation can be gauged using the NFS data presented in (Figure 20). Positive yield responses from the use of a cover crop are represented as values above the zero line and negative responses as values below. The values are ranked in order of response and not by year. The results suggest an interaction between cover crop yield response and tillage practice; with cover crop use in conjunction with shallow non-inversion tillage are more likely to give a positive yield response in this study. Interestingly, the only appreciable negative value in the shallow non-inversion tillage system was in 2014, where oilseed rape followed repeated use of a brassica cover crop (Stobart & Morris 2015). It is likely that the use of lower tillage intensity allows the benefits of the cover crops (i.e. rooting and improved soil structure) to be better utilised across the rotation. The effect of the cover crops is less likely to be apparent in a plough-based system as the mechanical disturbance by inversion tillage restructures the soil through physical and not biological means. Further information to the project can be found at: niab.com/research/agronomy-and-farming-systems/research-projects-agronomy-farming-systems/new-farming-systems

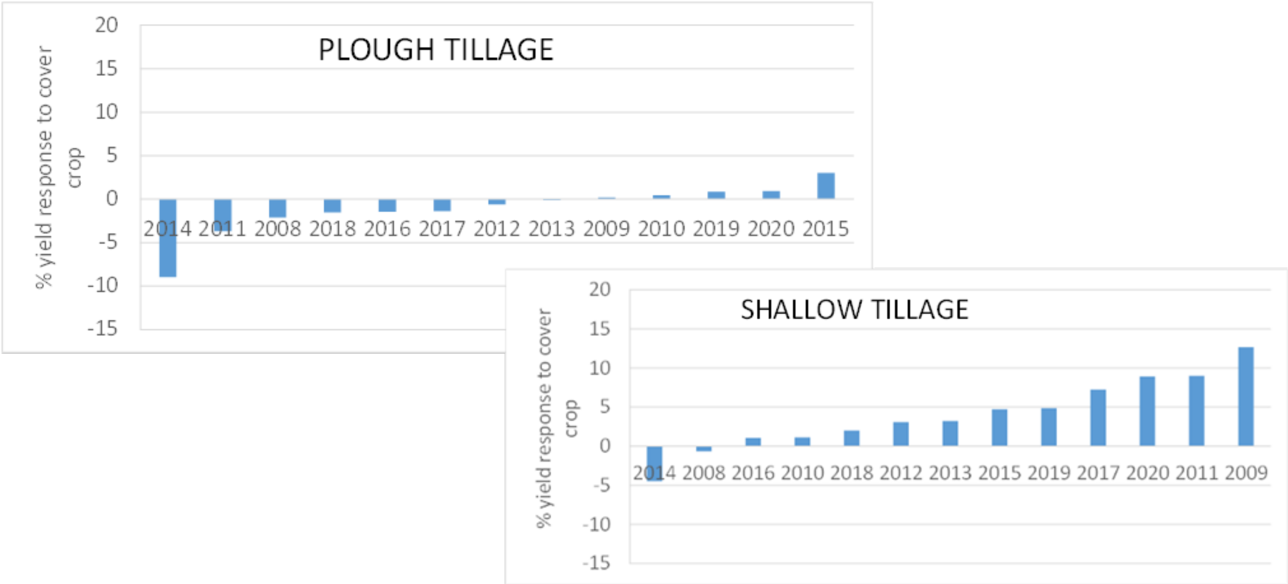


Figure 20. Yield response (%) to the rotational use of a brassica cover crop (grown before the spring sown break crops in the rotation) under a plough based or shallow non-inversion tillage system. Positive values are a benefit from rotational cover crop use. Crops in specific harvest years were: 2009 (spring oilseed rape), 2011 (spring beans), 2013 (spring barley), 2014 (winter oilseed rape), 2016 (spring oats), 2018 (winter barley) and 2010, 2012, 2015, 2017 and 2020 (winter wheat).

Wensum Demonstration Test Catchment (DTC):

Across the UK, three Demonstration Test Catchments (DTCs) were established with each concentrating on a different farming system. This Wensum DTC focuses upon the intensive arable River Wensum DTC in Norfolk, UK, where cover crops and non-inversion tillage methods were trialled as diffuse pollution mitigation measures on a large, commercial arable farm over a three-year period. Cropping is managed with a seven-year rotation of winter wheat, winter and spring barley, winter oilseed rape, spring beans and sugar beet. Several fields were ‘blocked’ to examine different tillage practices, including ploughing and non-inversion tillage (shallow non-inversion tillage and direct drilling). In addition to the different tillage regimes, two of the blocks were sown to an oilseed radish cover crop ahead of spring cropping. Results revealed oilseed radish cover crop reduced nitrate (NO_3) leaching losses in soil water by 75–97% relative to the fallow block, but had no impact upon phosphorus (P) losses (Cooper et al., 2017). Further information to the project can be found at: defradigital.blog.gov.uk/2016/09/21/demonstration-test-catchments-open-data

AHDB Strategic Cereal Farm South:

Work at the Strategic Cereal Farm South (Wheatsheaf Farming Company) has been investigating the interaction between the cover crop species mix, soil health status, and health and productivity of following spring crops. The work complements cover crop trial data collected by FWAG-South East on the farm looking at water quality. The farm has used cover crops ahead of all spring cropping since 2015. Data collected by FWAG-South East showed reductions in nitrate leaching where cover crops were grown. Further information to the project can be found at: ahdb.org.uk/on-farm-trials-at-strategic-cereal-farm-south-2021-2027

Other on-farm trials looking at cover crops and water quality:

South East Water: corporate.southeastwater.co.uk/about/our-environment/cover-crops/

Anglian Water: anglianwater.co.uk/siteassets/household/help-and-advice/nitrogen-retention-in-cover-crop-trial-.pdf

South Downs Farming Cluster group: southdownsfarming.com/networks/arun-to-adur-farmers-group

3.4. Action points for farmers and agronomists

- Cover crops in the rotation can be a valuable management tool for protecting the soil and reducing the losses to water
- However, cover crops need to be used as part of a 'toolbox' of management approaches, including changes to tillage practices, crop rotation and farming systems to maximise their benefits
- It is also likely that the repeated use of cover crops will allow for improved soil structure, water holding capacity, improved crop root architecture that allows for water and nutrients to be better accessed to the crop, which allows more resilience in the farming system

In summary, work has found that:

- Improving water quality on farm has many interactions both in terms of management (cultivation and rotation) and over-winter rainfall can significantly affect drain water concentrations
- Approximate average daily losses of nitrate from field drains varied from 0.1 to 1.8 kg N/day. This loss equates to £0.20 to £3.70/day based on AN fertiliser at £2.00 kg N

- There appears to be a linear decline in nitrate losses through tillage, decreasing tillage intensity (i.e. low soil disturbance) reduced nitrates by 55–66% compared to ploughing
- Grass, oilseed rape, winter barley and cover crops can reduce nitrate losses by up to 50%. However, this is dependent on cropping history.
- Cover crops can be part of a farm strategy that reduce drain water nitrate concentrations
- However, cover crops may release nitrate in subsequent seasons, where subsequent cropping may not utilise available nitrogen and lead to losses to water

4. Use of flowering strips (work package 3)

Trial leader: Aoife O'Driscoll, NIAM

Start date: 1 September 2022

End date: 31 August 2023

4.1. Headlines

- No two fields were alike in their composition of insect or plant species, although strips within fields were more similar than across fields
- Aphids numbers were consistently low throughout the study. This led to low numbers of aphid predators, such as hoverfly and lacewing larvae, that use floral resources in addition to their aphid food source. Numbers were too low to identify changes in abundance associated with the floral strips
- Slugs were found in all fields assessed and there was a slight trend across years for higher numbers in the field centre
- Predators of slug eggs, including beetles and spiders, benefitted from the grass habitats by using them as refuge from crop management later in the year and as winter habitat
- There was no clear evidence of an impact of distance into the crop on pest or beneficial insect abundance; though there is a lot of evidence from larger studies that the number of beneficial insects reduces further into the field
- The flowering margins made a significant difference to overall species richness, with the greatest abundance being where margins were adjacent to another habitat, such as a hedge, rather than a strip down the centre of the field

- Farm staff working the fields felt that adding a central strip made practical farming more difficult, it effectively added two more headlands and more turns making the field less efficient and productive
- Management options to increase beneficial populations need to be applied to fit each field, where possible, accounting for surrounding habitats, underlying conditions and management practices
- Prolonged spells of high temperatures and lack of rain during the June to August period resulted in some flower species not flowering after these hot, dry periods
- Recommended management strategies for floral areas usually involve cutting hard, removing or baling in the first years of establishment, however we found that areas uncut in the previous autumn delivered more flowers in the dry summer conditions
- The scale of monitoring and identification skills required to make reliable estimates of changes in insect numbers is time-consuming
- Despite this, there is a huge benefit in familiarising yourself with the various insects in and around your crop
- Don't spend a lot of time identifying individual species – the first step is being able to recognise the common insects in and around your farm.

4.2. What was the challenge/demand for the work?

Integrated pest management (IPM) is an important part of arable farming. Our previous research reported that non-crop habitats are important sources of biodiversity. This trial is looked at whether the results found in research trials are also seen on a commercial farm.

Flower strips attract insects that are beneficial for pollination and pest control. Field margins play an important role in enhancing insect predators and parasitoids. The trial investigated whether flower strips can help farmers to reduce their use of insecticides.

4.3. How did the project address this?

This field-scale trial used three fields: Big Guinea Row (BGR), Bottom 59 and Top 59. All were arable fields planted with wheat but had differing field margins. BGR had an established flowering margin around the field, Bottom 59 had the same but also had a central flowering strip down the middle of the field, Top 59 had no margins. Assessment points were mapped by GPS at the beginning of the study, then returned to and used repeatedly across seasons.

Figure 21. The three fields in the flowering strip trials

The margins were sown with an ESG1 and ESG2 mix (Emorsgate Seeds) that contains finer grasses suitable for creating flower-rich margins. 1 kg of ‘em5f’ (wildflowers for loamy soils) was also added into the mix prior to sowing (Table 23).

Table 23. Rate of sowing and % in the mix of the sown grass and flower species

Grass mix sown at 20 kg/ha		Flower mix sown at 6 kg/ha	
%	Species	%	Species
5	Common bent	12.5	Common knapweed
10	Crested dogstail	15	Wild carrot
20	Sheep’s fescue	15	Lady’s bedstraw
20	Slender creeping fescue	10	Oxeye daisy
20	Chewing’s fescue	12.5	Ribwort plantain
5	Small Timothy	5	Salad burnet
20	Smooth-stalked meadow grass	1.5	Selfheal
		6	Common sorrel
		10	Red campion

Figure 22. Some of the flower and grass species in the flower strips

Objective 1. Assessment of pests and natural enemies

We used assessment methods that can feasibly be undertaken by farmers. Slugs and ground dwelling natural enemies were assessed in early November and March. Slugs were monitored using simple bait traps; a teaspoon of bran covered with an inverted plant pot saucer, fixed to prevent it blowing away. To monitor ground dwelling invertebrates, we used pitfall traps consisting of a plastic pot inserted into the ground, partially filled with a saltwater solution to kill and preserve ground dwelling invertebrates.

Figure 23. Slug and pitfall traps

To monitor aerial invertebrates that live off the ground, we used water traps. These consist of 2.5 litre clear tubs, suspended slightly off the ground to catch invertebrates which can fly or have fallen from the crop. Similar to the pitfall traps, they are partially filled with a saltwater solution to kill and preserve these invertebrates.

Figure 24. Water traps

Objective 2. Assessment of floral strips and associated weeds

We monitored the establishment of the sown species within the strips, the appearance of non-sown species or weeds in the floral strips and encroachment of any of the sown plant species into the crop. Plant species numbers were counted in 9 x 0.5m² quadrats every 5m. Assessments were made within the flower strips and 1m from the flower strip into the crop. The assessment was carried out on 1 August 2023.

Figure 25. Flower and grass assessments within the margin

Objective 3. Assess the impact of in-field flowering strips on yield and margin

Removing land from crop production clearly has an immediate impact on overall yield, however there may be additional impacts on the adjacent crop. The fixed costs of establishing the floral strips were calculated. Yield and margin data for Bottom 59 over a 13-year period (harvest 2009 to harvest 2023) was used to quantify any yield and margin losses and/or gains because of installation of the in-field floral strip.

4.4. Results

Objective 1. Assessment of pests and natural enemies

Slugs and aphids:

Slugs were present in all fields, both close to the field margin and in the field center. There was a slight trend for higher numbers at the field margin edge, with the greatest number of slugs recorded at Bottom 59 in March. This was a different result to the two previous years of slug trapping where more were found in the center of the field, and the highest numbers were at Big Guinea Row. Aphids numbers were consistently very low, a trend observed across years at this farm. As such no data on aphid numbers is included in the report.

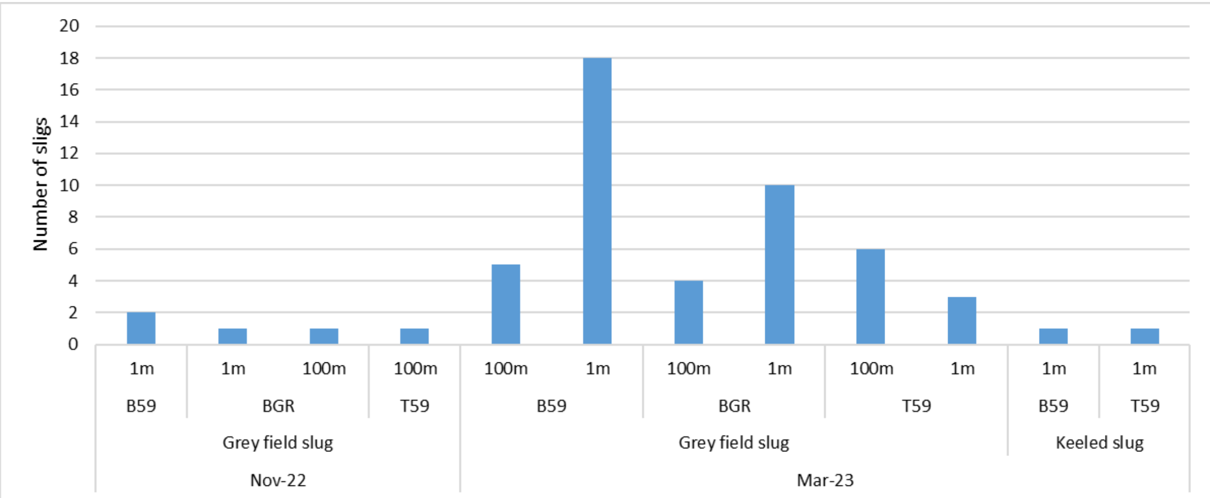


Figure 26. Sum of grey field slugs and keeled slugs recorded in November 2022 (post-crop emergence) and March 2023 for Bottom 59, Top 59 and Big Guinea Row. The assessments were made at 1m and 100m from the floral margin into the crop and 1m from the centre flower strip at Bottom 59

Ground beetles:

Approximately 20–30 species of ground beetles are important for biocontrol and 5–10 of these are abundant on farmland. Ground beetles are generalist predators, providing a background level of control for a wide range of pests including aphids, slugs and weed seeds. Installation of 'beetle banks' are beneficial for this group, which can readily migrate between non-crop and crop habitats. Figure 28 details numbers of the main ground beetle species identified in summer trappings during July 2023. Figure 27 includes photographs of some of the species identified. Various orders of ground beetle were identified from pitfall and water traps, including Harpalus, Trechus, Notiophilus, Poecilus and Pterostichus. Other species identified in single numbers (single traps across the three fields) include the violet ground beetle, the soft winged flower beetle, the carrion beetle, soldier beetles, false blister beetles and various species of leaf beetle. These are not included in Figure 28.

Figure 27. Some of the ground beetle species in water and pitfall traps in July 2023. Clockwise from top left: Poecilus, Harpalus, Copper greenclocks (Poecilus), Nebrius, Pterostichus, violet carabid beetle.

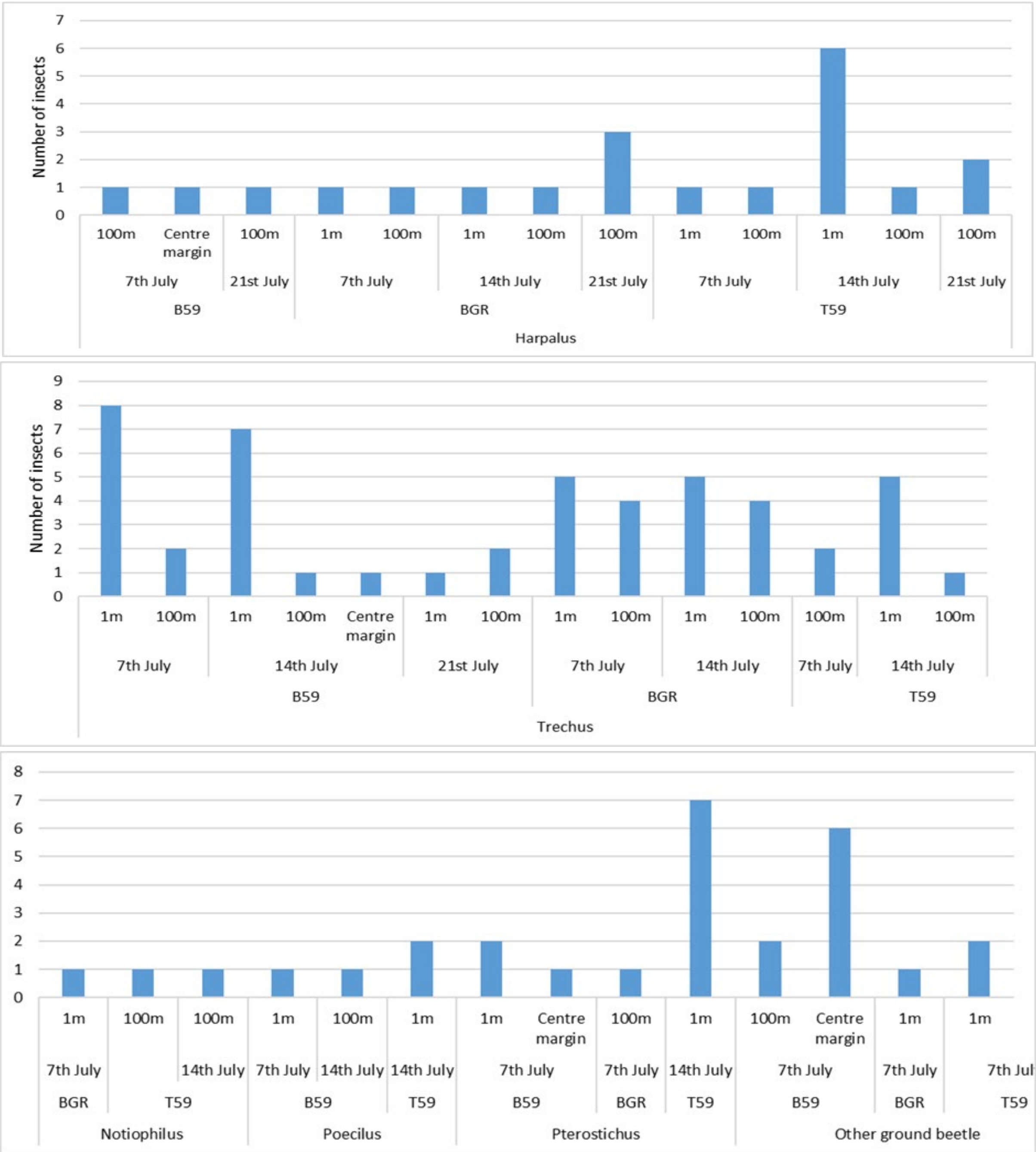


Figure 28. Sum of different ground beetle species recorded in water and pitfall traps at three time points in July 2023 for Bottom 59, Top 59 and Big Guinea Row. The assessments were made at 1m and 100m from the floral margin into the crop and 1m from the centre margin at Bottom 59.

Rove beetles:

Rove beetles are easily recognised as their wing cases are shortened, exposing their long, narrow segmented abdomen. They mostly feed at ground level as adults or in the soil as larvae. Rove beetles are especially vulnerable to insecticide sprays applied in the spring and autumn. Ploughing may not directly reduce numbers but rove beetle abundance and species diversity is higher in min-till systems. Figure 9 details numbers of the main rove beetle species identified in summer trappings at SFE during July 2023. The primary grouping identified was Tachyporus, with limited recordings of Ocypus in single numbers in up to 5 individual traps. These are not included in Figure 29.

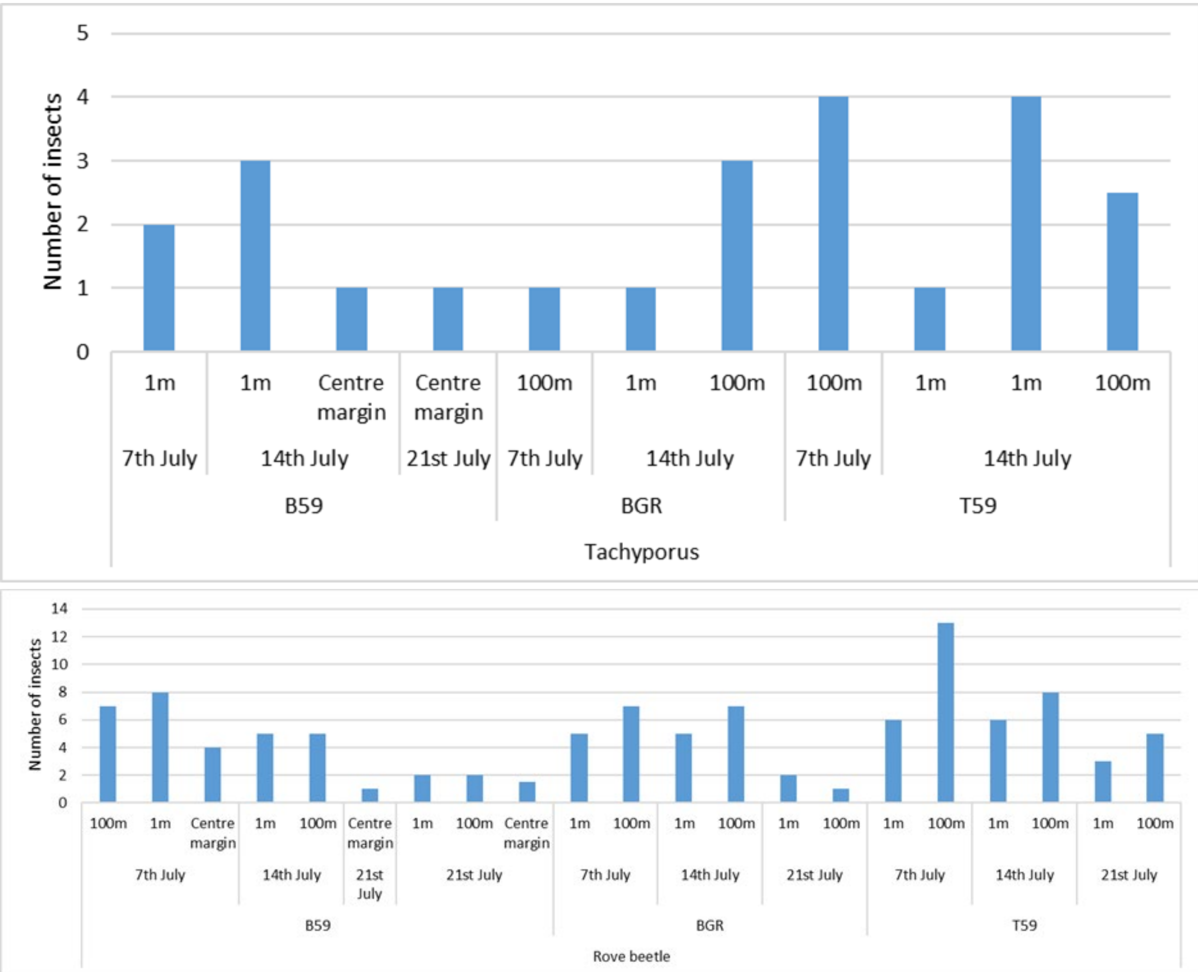


Figure 29. Sum of rove beetle species recorded in water and pitfall traps at three time points in July 2023, for Bottom 59, Top 59 and Big Guinea Row. The assessments were made at 1m and 100m from the floral margin into the crop and 1m from the center margin at Bottom 59.

Spiders:

Spiders provide background levels of control but the more mobile species settle in locations with sufficient prey, so exhibit some response to prey densities. Money spiders disperse by ballooning; floating on air currents suspended on a thread of silk that can trap a range of pests. Ground-dwelling spiders are active predators on the soil surface. Spiders are vulnerable to disturbance and prefer areas of dense, relatively undisturbed habitat. Reduced cultivations and provision of undisturbed habitat around the farm will improve numbers. Figure 31 details numbers of the main spider species identified in summer trappings in July 2023. Figure 30 includes photographs of some of the different species identified. The primary groupings identified were wolf spiders, orbweb spiders, crab and harvestmen spiders. Funnelweb spiders and comb footed spiders were also presented in single numbers in up to 5 individual traps. These are not included in Figure 31.

Figure 30. Some of the species identified in water and pitfall traps in July 2023. Left to right: Long-jawed orbweb spider, funnelweb spider, wolf spider, crab spider.

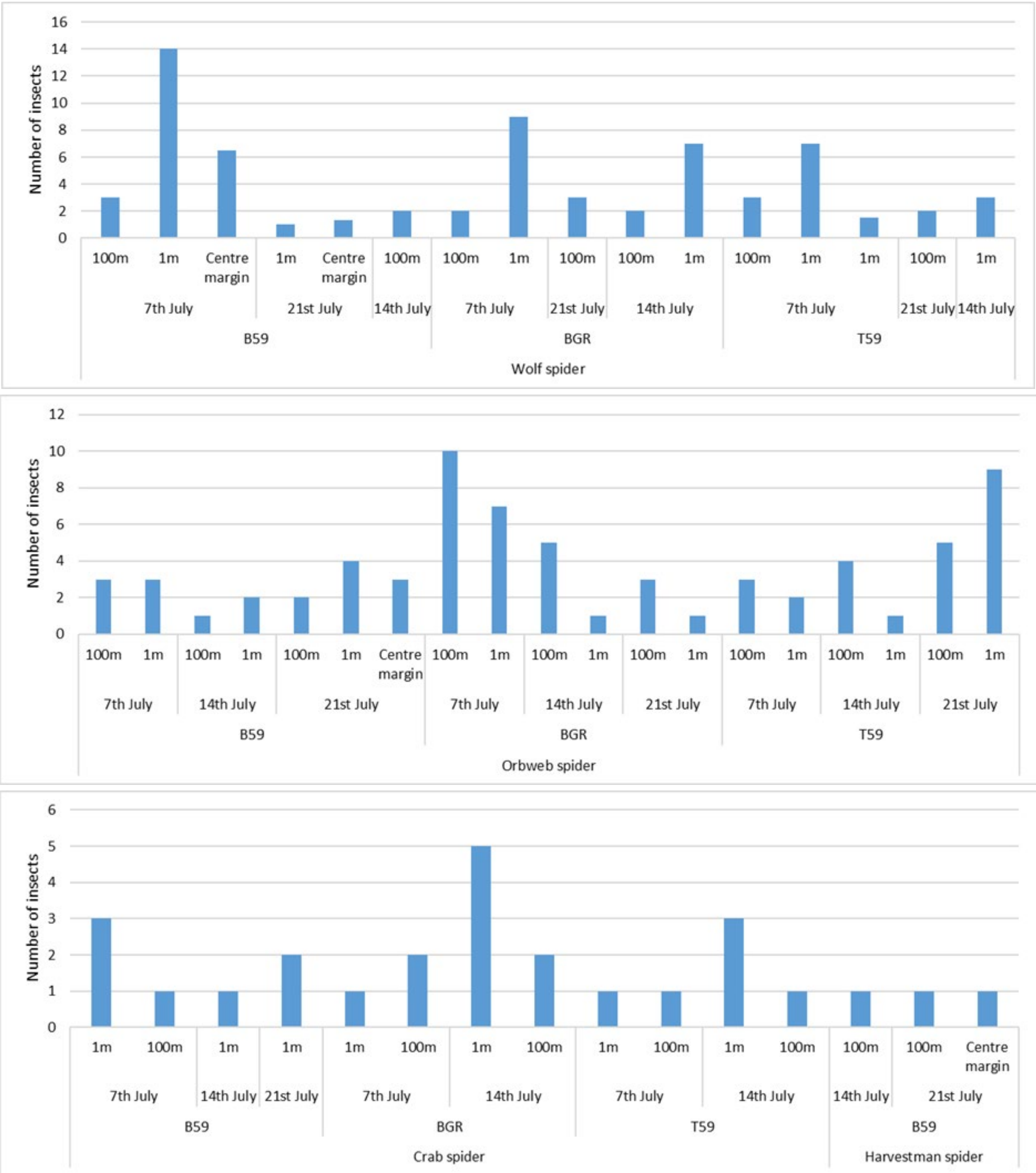


Figure 31. Sum of spider species recorded in water and pitfall traps at three time points in July 2023 for Bottom 59, Top 59 and Big Guinea Row. The assessments were made at 1m and 100m from the floral margin into the crop and 1m from the center margin at Bottom 59

Hymenoptera:

Hymenoptera is a large order of insects, comprising the sawflies, wasps, bees and ants. It encompasses insects with very different life forms. Many of the species are parasitic. Almost all crop pests have their own parasitic species that can provide sufficient natural control on farm. Figure 33 details numbers of the main species from the order Hymenoptera identified in summer trappings at during July 2023. Figure 32 includes photographs of some of the different species identified. The primary groupings identified were Ichneumon wasps, spider hunting wasps and social wasps. Several bee species were also identified, including bumblebee, furrow bee, honeybee and bees from the Hylaeus order. Digger wasps and a member of the Braconidae family of parasitoid wasps were also present in single numbers in up to five individual traps. These are not included in Figure 33.

Figure 32. Some of the wasp and bee species identified in water and pitfall traps in July 2023. Left to right: digger wasp, spider hunting wasp mining bee, a member of the Ichneumon wasp family, furrow bee

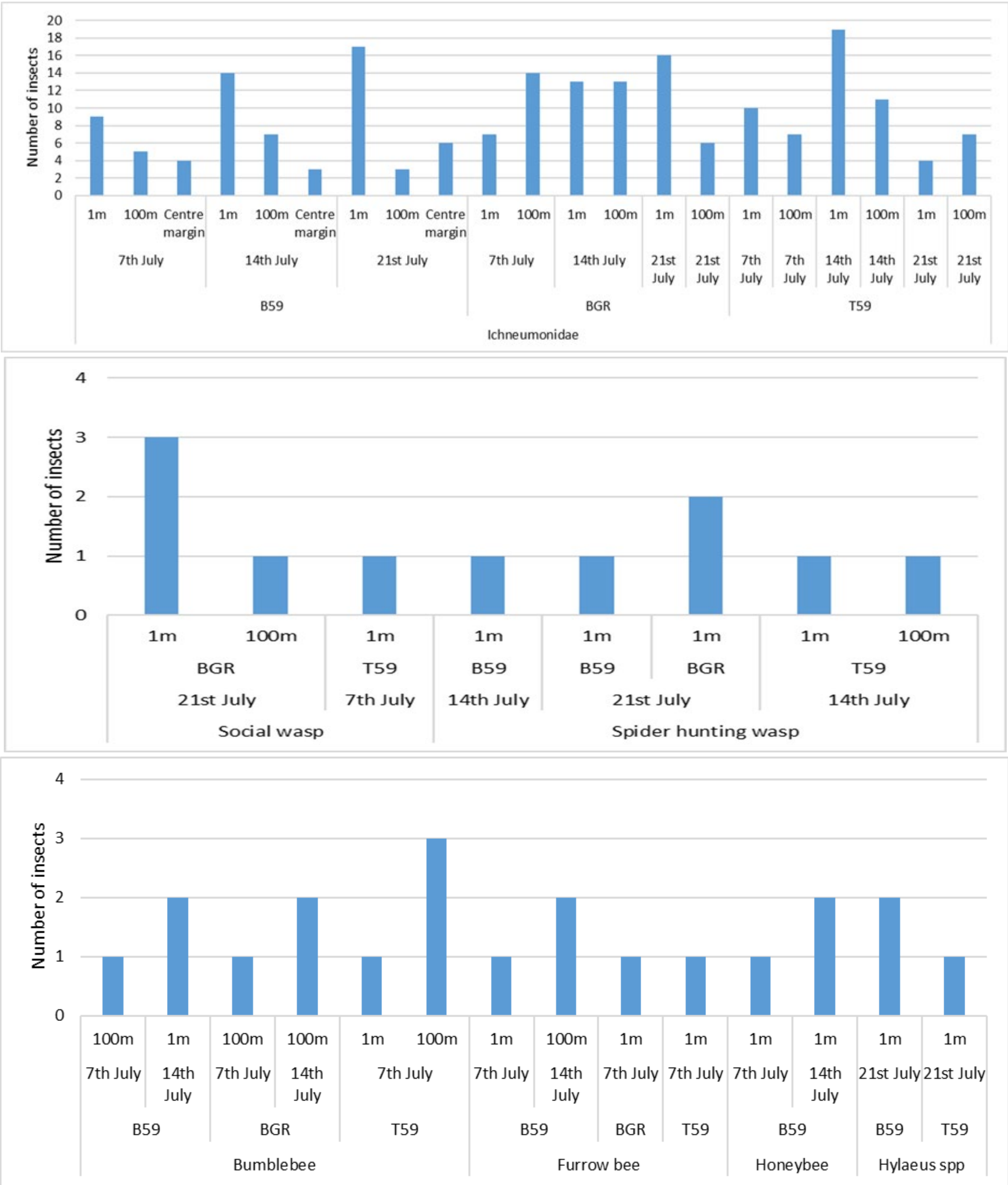


Figure 33. Sum of wasp and bee species recorded in water and pitfall traps at three time points in July 2023 for Bottom 59, Top 59 and Big Guinea Row. The assessments were made at 1m and 100m from the floral margin into the crop and 1m from the center margin at Bottom 59

Diptera:

Diptera is a very diverse order, with just over 7,000 species. Although there are numerous predatory fly species that are very common on farmland, relatively little is known about their ecology and contribution to pest control. Likewise, many species may pollinate flowers but their overall importance for pollination is poorly understood.

Flies also contribute to nutrient recycling of dung and vegetation. Figure 35 details numbers of the main species from the order Diptera identified in summer trappings during July 2023. Figure 34 includes photographs of some of the different species identified. The primary groupings identified were crane flies and dance flies, Tachinidae (parasitic flies), Empididae (dagger flies), Dolichopodida (long legged flies) and hoverflies.

Figure 34. Some of the species from the order Diptera identified in water and pitfall traps in July 2023. Left to right: long legged fly (order Dolichopodida), parasitic fly (order Tachinidae)

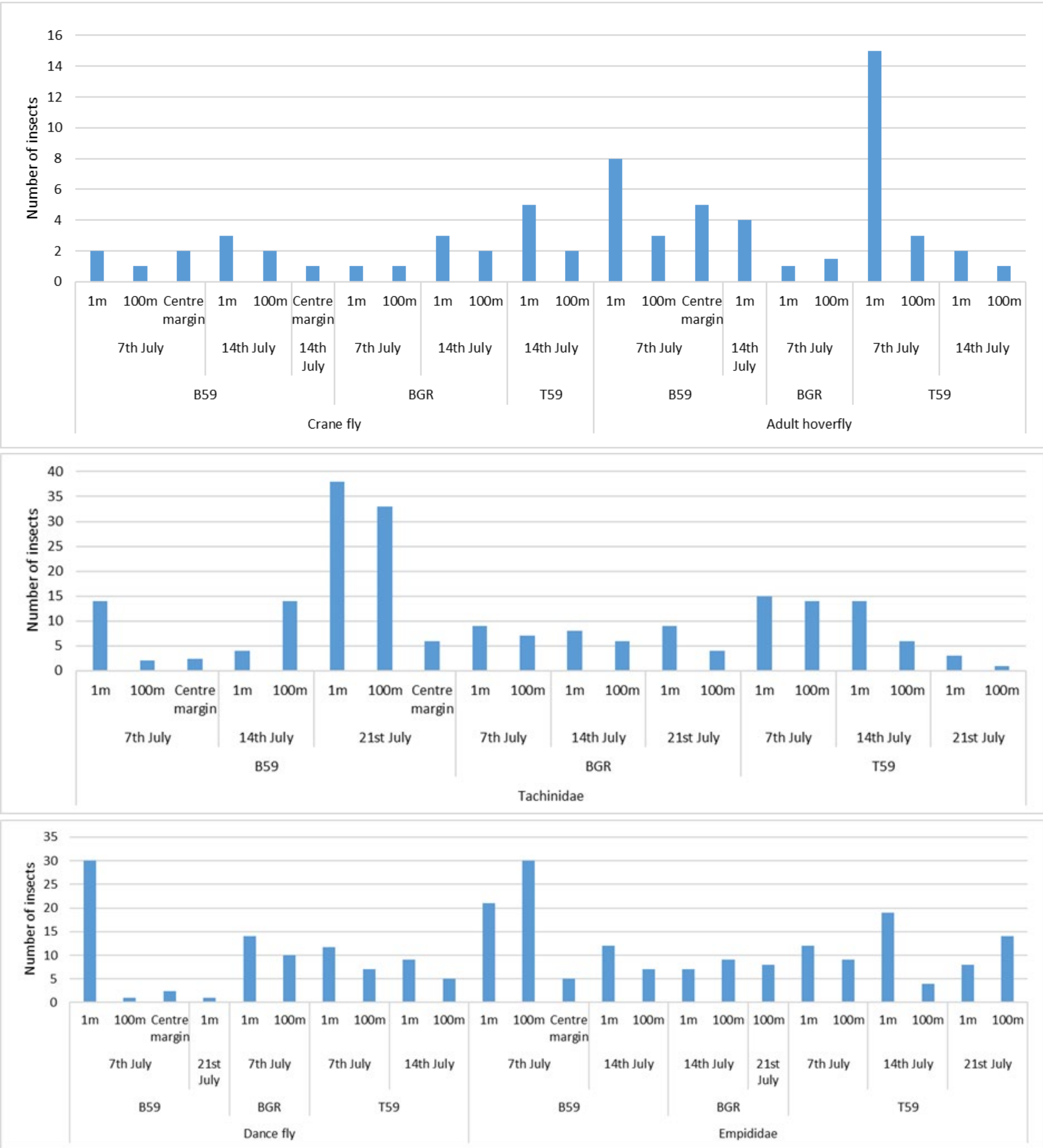


Figure 35. Sum of species from the Diptera order recorded in water and pitfall traps at three time points in July 2023 for Bottom 59, Top 59 and Big Guinea Row. The assessments were made at 1m and 100m from the floral margin into the crop and 1m from the centre margin at Bottom 59.

Objective 2. Assessment of floral strips and associated weeds

The frequency of species recorded in the margins are presented in Table 24. The most frequently occurring grass species were rye-grass, small Timothy, smooth stalked meadow grass and Yorkshire fog, with the most common flower species being common knapweed, wild carrot, ribwort plantain and yarrow. Other non-sown species found infrequently at different points in the crop margins included ploughman's spikenard, birds foot trefoil, cut leaved cranesbill and smooth hawksbeard. For both fields where floral margins were present there was a low to moderate level of encroachment of several grass species into the main crop. Most of this was sterile brome, present at 1m from the centre strip at Bottom 59. The study showed that in the first three years where strips were present, there was limited encroachment out of the strip into the main crop, but by the final year (harvest 2023) we were beginning to see movement of grasses into the main crop. This was not unexpected, and IPM tools exist to manage it, including the use of sterile strips, cultivations or specific herbicide applications.

Figure 36. Autumn 2020 and summer 2021 views of floral margins

Table 24. Percentage of species in 9 x 0.5m^2 quadrats within the margin (9 quadrats were assessed per edge on 1 August 2023)

Species	Bottom 59			Big Guinea Row	
	Edge 1	Edge 2	Centre strip	Edge 1	Edge 2
Grass species					
Ryegrass	22	33	56	44	11
Small Timothy	66	56	22	66	66
Smooth stalked meadow grass	77	77	77	56	77
Common bent	0	11	0	0	0
Sheeps fescue	33	0	0	33	0
Chewing fescue	0	0	0	0	0
Rye brome	33	11	0	0	0
Yorkshire fog	56	44	0	0	0
Flowers and non-grasses					
Common knapweed	66	100	100	77	66
Wild carrot	33	56	11	66	33
Oxeye daisy	0	22	44	22	11
Ribwort plantain	56	44	56	66	56
Salad burnett	33	0	0	0	0
Common sorrel	11	0	22	0	22
Red campion	0	11	0	0	0
Yarrow	77	44	0	56	66
Groundsel	0	22	33	0	0
Spear thistle	22	44	0	22	11
Cut leaved cranesbill	22	22	44	0	0
Vetch	0	0	11	0	0
1m in from the margin edge					
Sterile brome	33	44	100	0	0
Blackgrass	0	11	0	0	11
Ryegrass	11	0	33	0	0
Rye brome	11	0	0	0	0
Groundsel	11	22	11	0	11

Objective 3. Assess the impact of in-field flowering strips on the crop yield.

The estimated set up costs in establishing the grass and flower strips are outlined in Table 25. The estimated yield and margin loss due to area of the field taken out of production for the infield strips at Bottom 59 is detailed in Table 26. Average loss of income (£) across the rotation is estimated at £250 and for wheat only is estimated at £370/ha (based on wheat prices in November 2022 of £265/t).

Table 25. Costings for grass and flower strips establishment

Operation	Cost
Preparation of strips operation (4m discs/tines + power harrow + roll)	£100 /ha
Seed	£589.91/ha
Broadcast operation	£15/ha
Rolling operation	£10/ha
Total cost of establishment	£714.91/ha

Table 26. Average loss of income (£) across the rotation and wheat only, based on field average yields for Bottom 59 for the previous 13 harvest years (2009–2023). This calculation is based on a flower strip area of 445m x 6m taken out of the center of the field at Bottom 59.

Crop	Yield t/ha	Margin (£/ha)
Herbage Grass	1.1	511
Herbage Grass	1.3	1269
Herbage Grass	1.0	564
Herbage Grass	1.1	895
Hybrid Barley	9.7	652
Naked Oats	4.0	-111
OSR	5.3	306
Winter Wheat	10.4	597
Winter Wheat	12.9	780
Winter Wheat	8.6	51
Winter Wheat	10.5	691
Winter Wheat	9.8	1,674
Winter Barley	9.5	550
Average margin (£/ha)	648	
Area wildflowers (ha)	0.267	
Average loss income across the rotation (£/ha)	250	
Average loss income-wheat only (£/ha)	370	

4.5. Action points for farmers and agronomists

Pests and beneficials

No two fields were alike in their composition of insect or plant species, although strips within fields were more similar than across fields. Aphids numbers were consistently low throughout the study. This led to low numbers of aphid predators, such as hoverfly and lacewing larvae, that use available floral resources in addition to their aphid food source. However, numbers were too low to identify changes in abundance associated with the floral strips. Slugs were found in all fields assessed and there was a slight trend across years for higher numbers in the field center. Predators of slug eggs, including beetles and spiders, benefitted from the grass habitats by using them as refuge from crop management later in the year and as winter habitat. There was no clear evidence of an impact of distance into the crop on pest or beneficial invertebrate abundance; though there is a lot of evidence from larger studies that the number of beneficial insects reduces further into the field.

Assessment of floral strips

The flowering margins made a significant difference to overall species richness, with the greatest abundance where margins were adjacent to another habitat, such as a hedge, rather than a strip down the center of the field. Farm staff felt that adding a central strip made practical farming more difficult, it effectively added two more headlands and more turns making the field less efficient and productive. Management options to increase beneficial populations need to be applied to fit each field, where possible, accounting for surrounding habitats, underlying conditions and management practices. Prolonged spells of high temperatures and lack of rain during the June to August period resulted in some flower species not flowering after these hot, dry periods. Recommended management strategies for floral areas usually involve cutting and removing hard in the first years of establishment, however we found that areas uncut in the previous autumn delivered more flowers in the dry summer conditions.

Finally, the scale of monitoring, and identification skills required to make reliable estimates of changes in insect abundance is time consuming. Despite this, there is a huge benefit in familiarising yourself with the various insects in and around your crop. Don't spend a lot of time identifying individual species – the first step is being able to recognise the common insects in and around your farm.

5. Marginal land (work package 4)

Trial leader: David Clarke, NIAB

Start date: 1 September 2022

End date: 31 October 2023

5.1. Headlines

- Sampling areas, identified from yield map analysis, generally showed similar spatial variation in yield in 2023 compared to historic yield performance
- Zonal targeted sampling for soil health scorecard metrics can improve confidence that soil management is optimal across observed variation in crop and soil properties
- Low-yielding areas did not show significant build-up of P or K reserves, suggesting little environmental or economic gain from zonal management on the studied fields
- Grain nitrogen concentrations were below optimal (1.9%) in the majority (10/12) of sites and, for the second consecutive year, in the two in-field sites in Shrubbery field, suggesting for the high-yielding in-field sites a yield response to increased nitrogen rates might be expected above 200 kg N/ha

5.2. What was the challenge/demand for the work?

This work located areas of low productivity across the farm, identified the cause of variation, and assesses whether alterations in management practice can improve economic performance in these areas.

5.3. How did the project address this?

In 2021, yield maps were used to identify land most suitable for Environmental Land Management schemes, such as SFI options. This approach used a geospatial statistical technique called clustering on ten years of yield maps and field level economic data. Across 35 fields, 154 clusters/management zones were identified. Subsequently, 38 ha of the lowest-performing areas were entered into environmental schemes in 2022.

Despite some of the marginal areas of the farm being taken out of production, analysis demonstrated that, of the area remaining in arable production, 300 ha still had an average annual mean net margin loss of over £100 ha compared to the best performing part (zone/cluster) of the same field (Figure 37).

The study looked at a selection of fields and explored, through targeted soil and crop sampling, if management could be altered spatially to improve economic and environmental outcomes from these management zones. Specific questions addressed were:

1. Can the variation in zone performance be explained through targeted soil sampling?
2. Can any management practices be identified to improve economic performance of specific management zones?
3. Does the environmental risk change amongst zones?
4. Can management help deliver reduced environmental risk?

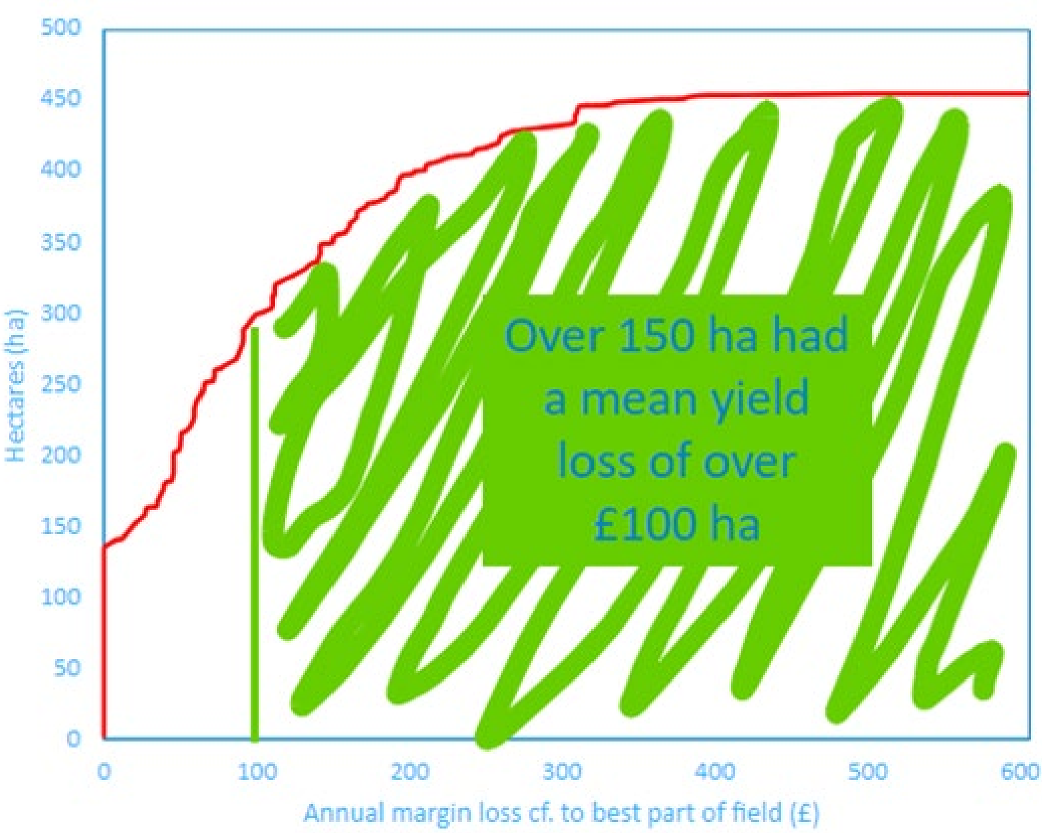


Figure 37. Area of farm compared to mean annual margin (£) loss compared to the best performing cluster/management zone in the same field

In 2022, 12 sites were identified across three fields (six in wheat, six in winter barley). In 2023, to make comparisons and trends easier to identify, all sites sampled were in winter wheat. A total of 12 sites across four fields were sampled in 2023: Top 59, Shrubbery (also monitored in 2022), Rushbottom field and long meadow field.

Figure 38 shows the four fields and the location of the sampling sites within their respective cluster (management zones) identified through yield map analysis in 2021. The long-term wheat yield performance of each cluster is reported in Figure 39. In Shrubbery, Kells and Rushbottom field a headland site (S3, K3, R3) was included, as these have historically been the lowest yielding parts of the field and 2022 results suggested nitrogen rates could potentially be lowered on these lower yield potential areas.

Figure 38. Fields sampled in 2023: S = Shrubbery, K = Kells, L = Long meadow, R = Rushbottom. Cluster number in order of long-term margin (1= most profitable)

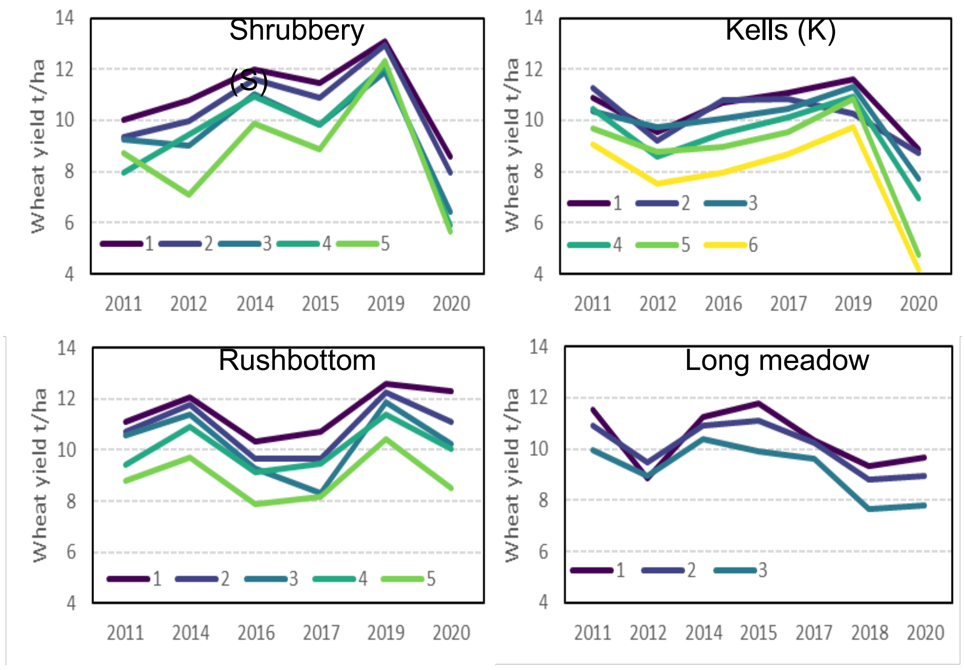


Figure 19. Cluster (see Figure 38) mean wheat yields 2011–2020

Assessments

Table 27 outlines the monitoring program carried out on all sites. Most of these are key components of the soil health scorecard. The farm is attempting to reduce overall nitrogen use to improve environmental outcomes and protect from price volatility. Since a peak in 2015 and 2016 of around 250 kg N ha, the farm has reduced N rates to around 200 kg N ha (Figure 40).

Table 27. Site monitoring protocol in 2023

Assessment	Timing
Soil nutrients, pH, OM and texture	Autumn 2022
VESS, Earthworms	Spring 2023
Tissue nutrient Test	Early June 2022 (GS30)
SPAD reading	Early June 2022
Ear counts	Early June 2022
Grain nutrient content	August 2023
Soil N Post Harvest	August 2023
Yield (Yield maps)	September 2022

In 2023, all fields monitored received 200 kg N ha. To test if nitrogen management is appropriate for all management zones, crop sampling was focused on measures to identify variation in nitrogen use across the sites. Leaf tissue testing was carried out at GS 30 and GS 69. At GS 69, headcounts and SPAD meter readings were also carried out. Soil N post-harvest was measured at each site, it can be expected that areas that are over-fertilised with N will have higher post-harvest soil N as the crop has utilised a smaller proportion of fertiliser N. Grain nutrient content, including N, was measured using a sample collected from three 1m^2 quadrats at each site.

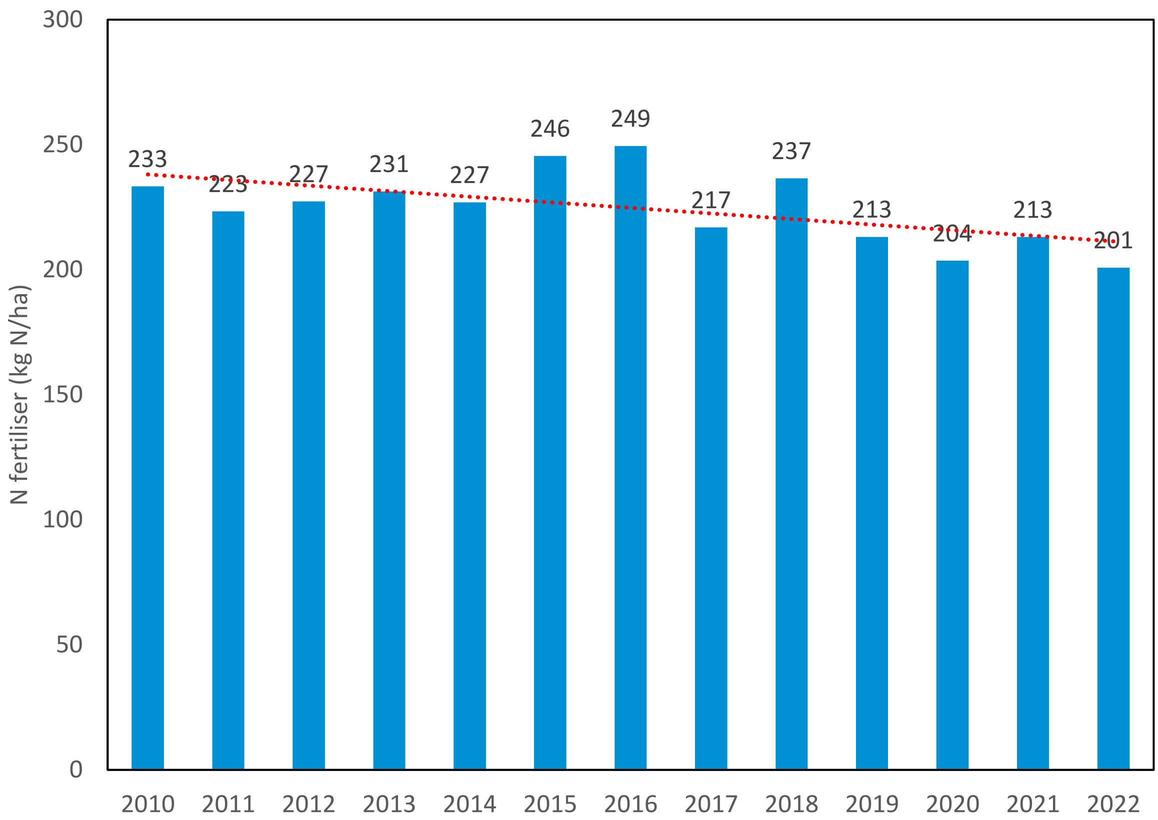


Figure 20. Average N fertiliser applied (kg N/ha) across the whole farm for winter wheat

5.4. Results

Yields

Yields were measured using combine yield maps. To obtain individual sampling site yields, the mean of all yield points (adjusted to 15% moisture) was taken from a 15m radius around the sampling locations.

Figure 41 shows the yields for 2023. Despite being a second wheat, the highest yields were obtained in Shrubbery field. Across all fields, the headland sites (S3, K3, R3) were the lowest yielding sites, ranging from 1.3 to 2.0 t/ha lower than the highest yielding site within each field.

Figure 42 shows the relative yield performance of each site compared to the average standardised yield of the cluster/management zone they are situated in. The strong relationship (r2=0.89) demonstrates that:

1. For the sampling sites selected, yield performance is representative of the wider cluster area that they are situated in
2. The 2023 yield variation across sites within each field has followed similar trends to historic variation, suggesting the influences of spatial variation in yield in 2023 are consistent with those that have historically driven this variation

Figure 43 shows the 2023 yield maps for each field. L1 site was situated in an area that was sprayed out for black-grass and therefore was moved approximately 30m north, still within the same cluster.

Figure 41. 2023 winter wheat sampling site yields

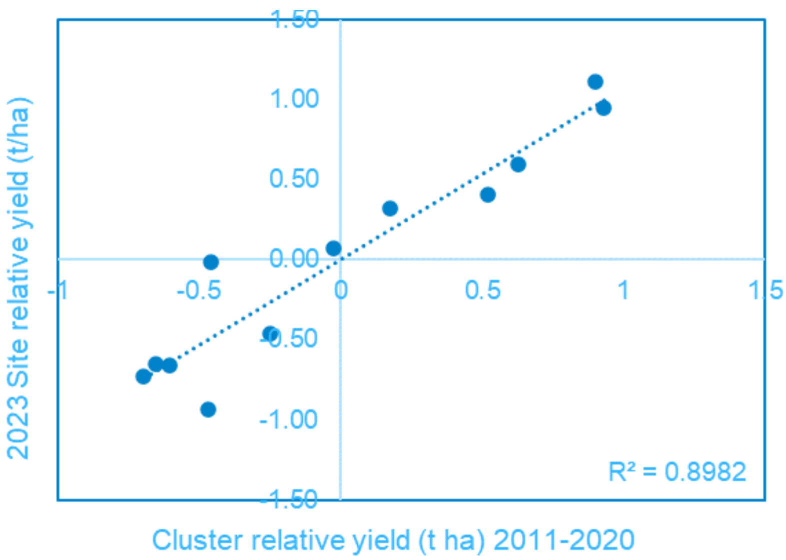


Figure 42. The relative (standardised to mean = 0, SD=1) yields for long-term average cluster performance and 2023 winter wheat site yields

Figure 43. Yield maps for the 2023 wheat crops (yellow low-yielding, blue high-yielding)

Soil health scorecard

The AHDB soil health scorecard presents core soil health indicators and compares them to typical ranges for UK soil types and climate regions (benchmarks).

Table 28 shows the soil health scorecard for the 12 sampling sites. Benchmarks are for a medium soil type in the east of England.

Virtually all (11/12) sites had P indices at or above index 2 and all the sites had a K index above 2-. This suggests that current P and K management (uniform applications across field) is not majorly disproportionate to variation in offtake. However, for Kells and Rushbottom field, the headland sites (K3 and R3) are an index 3 for P suggesting potentially offtake is slightly lower than applied and should continue to be monitored. The high-yielding site (S1) in shrubbery field is an Index 1, suggesting offtake is slightly higher than the other sites and should continue to be monitored.

Magnesium is an index 1 for 7 of the 12 sites and all sites in long meadow field. Magnesium deficiency can be an issue on soils with high sand content, and the farm is currently attempting to alleviate this issue by in season applications of Magnesium sulphate (Bittersaltz).

Soil organic matter is at benchmark levels for this soil type at all sites. However, there is some variation within and across fields, noticeably the low-yielding site at the top of long meadow field has a SOM 1.3–1.6%, lower than the other two sites sampled in that field.

Earthworm numbers are generally good, although Rushbottom field appears to have lower earthworm numbers, despite the highest SOM. Further sampling is recommended to see if this is consistently lower, further biological measures such as CO_2 burst could also be performed.

VESS Scores are below 2.5 for all infield sites and soil function is not expected to be restricted. However, the headland sites on Kells and Shrubbery field are above a 2.5 VESS score, suggesting root restricting levels of compaction. This is likely to be expected on these turning headlands and likely the cause of the lower yields in 2023 and historically. Variation in texture is small across all sites and doesn’t appear to be a driver of yield variation.

Table 28. Soil health scorecard for the 12 sampling sites, continue rotational monitoring (green), review (yellow), investigate (red)

Site	Chemistry				Biological		Physical			
	P	K	Mg	pH	Earthworms	SOM	VESS	Sand	Silt	Clay
K1	20.4	176	49.3	7.3	12.0	4.3	1.7	68	16	16
K2	15.6	169	59.0	6.9	17.7	4.6	2.1	70	14	16
K3	33.6	137	59.4	6.8	14.0	4.0	2.5	67	15	18
R1	21.6	163	46.6	7.3	5.3	5.7	1.6	74	13	13
R2	20.0	176	49.0	7.1	4.0	5.4	1.6	70	15	15
R3	31.4	187	59.0	7.3	6.0	6.3	2.2	55	21	24
L1	23.4	145	46.5	7.4	10.0	5.8	1.6	65	17	18
L2	18.2	301	44.5	8.0	8.3	5.5	1.9	63	17	20
L3	12.8	166	45.4	7.4	9.0	4.2	2.0	70	14	16
S1	14.0	131	41.5	7.1	6.3	3.9	1.4	68	16	16
S2	22.0	120	51.5	6.9	12.0	4.3	1.8	70	14	16
S3	18.4	202	52.4	7.7	11.0	5.0	2.6	67	15	18
Mean	21.0	173.1	50.3	7.3	10	4.9	1.9	67	16	17

Grain P, K and Mg content

By comparing soil and grain nutrient content it is possible to identify if soil deficiencies are likely to be impacting crop growth or if there are other limiting factors affecting crop nutrient uptake (Figure 44).

Although guidelines for optimal grain nutrient content are less robust than that of soil indices. Despite most sites having a soil P index 2 or above only K1 had a grain P concentration above 0.32% considered optimal for cereals. Although this could be a season effect, if this pattern was to repeat over several seasons it would warrant further investigation.

The majority (10/12) of sampling sites had adequate soil K and grain K concentrations. Grain manganese concentrations were below those considered optimal in 8 of the 12 sites, in 6 of these sites soil Mg was also low (Index 1) therefore nutrient supply to the crop is likely to be limiting as previously discussed.

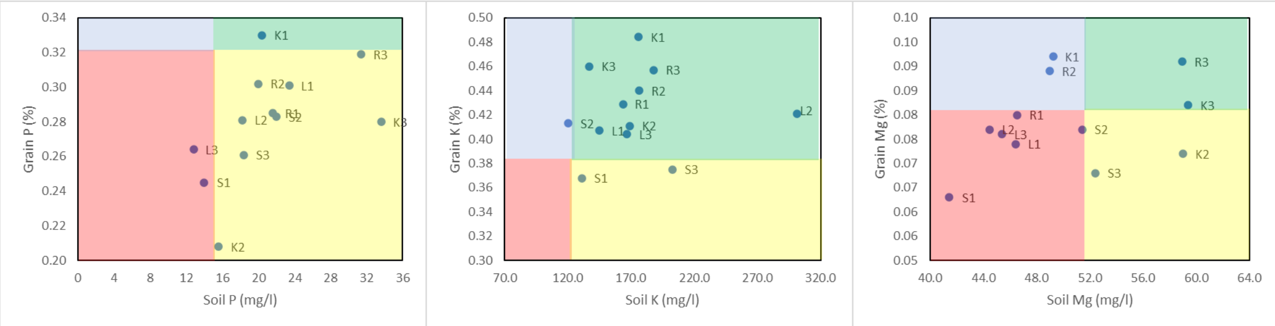


Figure 44. Soil nutrient concentrations compared to grain nutrient concentrations. Coloured boxes represent interpretations, low soil indices and low grain nutrient concentrations (increase soil concentrations), low soil concentrations but optimal grain nutrient concentrations (monitor), optimal soil concentrations but low grain concentrations (are other limiting factors hindering uptake), optimal grain and soil concentrations (crop unlikely to be limited).

Measurements related to nitrogen management

Table 29 reports the crop properties for each of the sampling site. Head numbers where generally good across all sampling sites, ranging from 498 – 623 heads /m^2, and should support a high yield potential.

RB209 suggests that farm N strategies can be assessed using grain protein/N concentrations as a guide. Research suggests that for feed wheats grain N concentrations of 1.9% (11% grain protein) is optimal for yield. If consistently below this value, then N rates could be adjusted by 30 kg N/ha per 0.1% grain N. Grain N concentrations were below 1.9% in 10 of the 12 sites sampled in 2023. However, except for shrubbery, field N concentrations were not higher in the lower-yielding sites, as one might expect from a yield-dilution effect. Shrubbery field was monitored in 2022 when in 1st wheat and showed a similar pattern to this year (Table 30). The two infield sites had grain N concentrations below 1.9% suggesting that the current farm standard N rate of around 200 kg N/ha might be slightly below that optimal for yield. However, on the lower yielding headland site, optimal grain N concentrations were achieved at this rate.

It is recommended that a tramline trial tests if a yield and grain N response is seen at N rates above 200 kg N/ha to guide management decisions. If N was below optimal for yield, this might explain the low grain P concentrations observed. Previous work has shown that P uptake is reduced with sub-optimal N rates and optimal soil P increases at lower N rates.

Only small differences were observed in plant tissue N tests within fields at both timings. However, at GS 69 there is a strong correlation (r^2 = 0.87) between SPAD meter readings and leaf tissue N concentrations. This does show the value in handheld N testers for capturing spatial variation in crop N uptake but should also be interpreted with canopy size, head numbers and yield potential. AHDB Strategic Cereal Farm Scotland has done further work comparing handheld N meters and tissue testing.

Variation in post-harvest soil N also showed little spatial patterns across fields. Very little variation was recorded in Kells field. While L1 was significantly higher than the rest of the field sites, this was sampled from an area sprayed out for black-grass control earlier in the season and therefore is reflecting lower N uptake from reduced crop growth. All other measures were taken from an area nearby that was not impacted by grass weeds. Rushbottom field shows spatial patterns more likely to be expected with the low yielding headland site, with reduced grain N uptake recording the highest post-harvest soil N. While Shrubbery field had the highest post-harvest soil N at the high-yielding site.

Table 29. Crop properties for each sampling site in 2023 and the standardised winter wheat yield performance for 2011–2020

Site	Standardised yield (2011–2020)	GS30 Leaf N (%)	GS69 Leaf N (%)	GS69 SPAD	Heads/m^2	Grain N (%)	Yield (t/ha)	Grain N uptake	Post harvest soil N (kg/ha)	SOM (%)
K1	0.4	4.2	3.2	53	540	1.6	11.5	153.8	56	4.3
K2	-1.1	4.4	3.2	50	607	1.5	9.9	129.7	56	4.6
K3	-1.1	3.9	3.2	49	498	1.6	9.5	131.2	62	4.0
L1	0.6	4.2	2.8	43	546	1.9	10.8	173.0	146	5.8
L2	0.4	4.1	3.0	48	586	1.8	10.8	163.2	81	5.5
L3	-0.5	3.9	2.8	45	580	1.6	9.7	132.1	88	4.2
R1	0.6	4.0	2.7	39	586	1.6	10.4	144.0	63	5.7
R2	0.4	4.0	2.6	42	553	1.8	9.9	149.2	73	5.4
R3	-1.1	4.2	2.9	48	533	1.7	9.1	132.3	92	6.3
S1	0.5	4.8	3.7	55	530	1.7	12.0	169.8	92	3.9
S2	-0.5	4.7	3.5	54	527	1.7	11.0	157.8	58	4.3
S3	-1.3	4.6	3.6	57	623	1.9	10.1	161.2	78	5.0

Table 30. Crop properties and soil organic matter for monitoring sites in shrubbery field in 2022 and 2023

Year	Site	GS30 Leaf N (%)	Heads/m^2	Grain N (%)	Yield (t/ha)	SOM (%)
2022 (1ST WW)	S1	4.91	321	1.8	12.4	4.3
	S2	4.82	340	1.8	11.4	4.3
	S3	5.35	339	1.9	12.1	5.1
2023 (2ND WW)	S1	4.76	530	1.7	12.0	3.9
	S2	4.74	527	1.7	11.0	4.3
	S3	4.55	623	1.9	10.1	5.0

5.5. Action points for farmers and agronomists

- Use yield maps or other spatial data sets, such as satellite imagery or proximal soil scans, to target soil health scorecard measurements across observed variation
- The above allows for greater confidence that soil management strategies are optimised across the variation observed
- By repeating targeted crop and soil measurements across years (as done with shrubbery field), nitrogen management strategies can be assessed and further explored