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Crop Production in Southern Britain: Precision Decisions for Profitable Cropping

The impact of cover crops on yield and soils in the New Farming Systems programme

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Summary

The New Farming Systems (NFS) research project is being undertaken on a sandy loam soil at Morley (Norfolk, UK). The programme is funded by The Morley Agricultural Foundation and The JC Mann Trust. The research is a series of large scale, long term, replicated experiments. The project is examining how we might improve the sustainability, stability and output of conventional arable farming systems. The systems being evaluated feature a range of cover cropping approaches; including the use of long term clover bi-crops, brassica cover crops and legume mix based cover crops (used ahead of spring sown crops in the rotations). The research has demonstrated benefits in terms of enhanced soil characteristics, positive yield responses and improvements in financial margins over fertiliser input associated with the use of specific cover crop approaches. This suggests that the incorporation of cover cropping approaches into rotations has the potential to contribute to agricultural production and to deliver wider benefits to future farming systems. However, the range of cover cropping options assessed differ in their management requirements and likely end results and the choice of species should be guided by particular circumstances and the desired goal.

Key words: Cover crop, farming systems, management, soils, sustainable, tillage

Introduction

The New Farming Systems (NFS) research programme is an ongoing series of long term and fully replicated field studies seeking to develop bio-sustainable approaches to conventional arable cropping. The NFS programme is funded by The Morley Agricultural Foundation (TMAF) and The JC Mann Trust and is being carried at Morley (Norfolk, UK) on a sandy loam soil (Ashley series). Research within the NFS programme is examining three inter-related themes: fertility building, tillage systems and soil amendments (Stobart & Morris, 2011, 2013). This paper considers aspects of the cover cropping research within these strategies and specifically how such approaches can contribute to soil structural improvement, enhancement of fertility and yield responses.

Materials and Methods

The NFS long term field studies began in autumn 2007. Experiments are fully replicated large plot studies with permanent grass pathways on the site allow plots to be accessed independently. The research programme uses conventional, practical farming approaches, and all experiments are based on a complete or incomplete factorial design with four replicates. Drilling dates vary according to season but crops (and cover crops) are sown in keeping with local best practice and seed rates are appropriate for the prevailing conditions. All other inputs are consistent with local best practice.

'Rotations' experiment

The experiment is a fully replicated incomplete factorial design using large plots and farm scale equipment/techniques. The main plot areas are 12 m × 36 m, with each plot subdivided into three 12 m × 12 m areas to examine nitrogen dose interactions; in total the experiment has 10 treatments (Table 1). The experiment uses a shallow non-inversion establishment technique (typically targeting *c*. 15 cm depth using disc and/or tine based approaches). Further details on this experimental method and design are presented in Stobart & Morris (2011, 2013).

'Cultivations' experiment

This experiment is examining the interaction of cultivation method and cover crop on crop performance. Four different cultivation methods are repeated with and without the presence of a deep rooted cover crop (grown ahead of spring sown crops); this forms part of a fully factorial design delivering eight treatments. A summary of treatments is set out in Table 2 with further detail in Stobart & Morris (2013).

Cover crop species and management

The brassica cover crop used in both studies is a fodder oil radish (*Raphinus sativus*). In the 'rotations' study the legume species mixture is based on a wide ranging 'All Species Mixture' (ASM) developed within Defra Sustainable Arable LINK project (Döring *et al*., 2013); the current mix uses white clover, trefoil (black medick), lucerne and crimson clover. Where adopted both cover crops were sown at 10 kg ha^{-1} typically in late August or early September and were destroyed and incorporated pre-drilling of the spring crop. The legume bi-crop system in the 'rotations' study was a small leaf white clover (cv. AberPearl sown in August 2007 and allowed to naturally regenerate each season); inputs to the bi-cropping system have otherwise been as the 'current practice' system.

Table 1. *Treatment and rotational progression details for the 'rotations' experiment*

<u>*Three rotations*</u>

System	Rotation	Cropping and harvest year				
		2008 (Year 1)	2009 (Year 2)	2010 (Year 3)	2011 (Year 4)	2012 (Year 5)
1	Winter break	ww	wosr	ww	wbn	ww
2	Spring break	ww	sosr	ww	sbn	ww
3	Mixed cropping	sw	sosr	ww	wbn	ww

Cropping key – ww (winter wheat), sw (spring wheat), wosr (winter oilseed rape), sosr (spring oilseed rape), wbn (winter bean), sbn (spring bean).

<u>*Four management systems*</u>

a) Current; rotations 1–3 run as standard with regard to inputs and husbandry.
b) Legume (clover bi-crop); rotations 1–3 using white clover as a legume bi-crop.
c) Current plus a brassica cover crop (fodder oil radish); rotation 2 and 3 only, with autumn cover crops prior to a spring sown crop.
d) Current plus a legume cover crops (legume species mixture); rotation 2 and 3 only, with autumn cover crops prior to a spring sown crop.

Three Nitrogen (N) management

N doses are applied across treatments as a banded dose i.e. each plot 36 m × 12 m plot is sub-divided into 12 m × 12 m sub-sections and each sub-section receives one of the following N doses:

i. Untreated (0% of standard dose) for the crop being grown.
ii. Half dose (50% of standard) for the crop being grown.
iii. Full dose (100% of standard) for the crop being grown.

Results

Key results from the 'rotations' and 'cultivations' experiments are presented in the following section.

'Rotations' experiment

Selected data are presented for the 'spring' and 'mixed' rotations for winter wheat in harvest years 2010 and 2012. The cover cropping regimes were not all in place for harvest year 2008 (when the study was first in wheat). The 'winter break' rotation has been excluded from this analysis as this rotation does not include all of the cover crop comparisons.

Soil assessment data from the 'NFS rotations' study demonstrates improvements in infiltration rates associated with the clover bi-crop approach; with Fig. 1 indicating increases from 0.78 mm min^{-1} (standard practice) to 2.19 mm min^{-1} (clover bi-crop system) recorded in 2012.

The yields presented in Table 3 are from winter wheat in harvest years 2010 and 2012 from the 'spring break' and 'mixed cropping' rotations; these two wheat cropping years follow similar rotation, cover cropping and establishment systems. The yield responses achieved in winter wheat (t ha^{-1}) above 'standard practice' in 2010 and 2012 are also described in Table 4. The margin over nitrogen (N) for all the cover crop approaches in 2012 are presented in Fig. 2.

'Cultivations' experiment

The yields of the NFS winter wheat from harvest years 2008, 2010 and 2012 is presented in Table 5. Fig. 3 outlines the mean yield responses associated with cultivation and cover crops use from selected NFS treatments in 2012. Changes in margin for harvest 2012 (following two cycles of cover cropping) are presented in Table 6.

Table 2. *Treatment and rotational progression details for the 'cultivations' experiment*

Rotation

	2008 (year 1)	2009 (Year 2)	2010 (Year 3)	2011 (Year 4)	2012 (Year 5)
Spring breaks	ww	sosr	ww	sbn	ww

Cropping key – ww (winter wheat), sosr (spring oilseed rape), sbn (spring bean).

Management

i. Current; systems run as standard with regard to fertiliser inputs.
ii. Cover crops; as 'i' but with a fodder/oil radish cover crop autumn sown and destroyed overwinter ahead of spring sown crops.

Cultivation

a) Annual plough: Treatment is ploughed every year.
b) Shallow tillage: treatment is cultivated to ≈5–10 cm using a non-inversion technique.
c) Deep tillage: Treatment is cultivated to ≈20–25 cm using a non-inversion technique.
d) Managed approach: Cultivation regime decided annually, based around soil conditions/assessments, previous cropping, weed burden and local best practice.

Table 3. *The effect of rotational cover crops inclusion on wheat yields (t ha^{-1}) in the New Farming Systems 'rotation' study in 2010 and 2012*

Yield (t ha^{-1})		2010			2012			Mean			Standard Deviation		
	% N Dose	Spring	Mixed	Mean	Spring	Mixed	Mean	Spring	Mixed	Mean	Spring	Mixed	Mean
Current	0	4.36	4.09	4.23	7.51	7.93	7.72	5.94	6.01	5.97	2.23	2.72	2.03
	50	6.81	6.80	6.81	10.53	10.98	10.76	8.67	8.89	8.78	2.63	2.96	2.29
	100	9.14	8.95	9.05	10.86	10.95	10.91	10.00	9.95	9.98	1.22	1.41	1.08
	Mean	6.77	6.61	6.69	9.63	9.95	9.79	8.20	8.28	8.24	2.02	2.36	1.80
Bi-crop	0	5.26	5.79	5.53	8.73	9.48	9.11	7.00	7.64	7.32	2.45	2.61	2.10
	50	7.52	7.42	7.47	10.90	10.86	10.88	9.21	9.14	9.18	2.39	2.43	1.97
	100	9.67	8.95	9.31	10.97	10.87	10.92	10.32	9.91	10.12	0.92	1.36	0.98
	Mean	7.48	7.39	7.44	10.20	10.40	10.30	8.84	8.90	8.87	1.92	2.13	1.66
Radish	0	4.62	4.05	4.34	8.18	7.56	7.87	6.40	5.81	6.10	2.52	2.48	2.07
	50	7.35	6.74	7.05	10.98	10.79	10.89	9.17	8.77	8.97	2.57	2.86	2.23
	100	9.03	8.88	8.96	11.01	10.92	10.97	10.02	9.90	9.96	1.40	1.44	1.16
	Mean	7.00	6.56	6.78	10.06	9.76	9.91	8.53	8.16	8.34	2.16	2.26	1.82
Legume mix	0	4.14	4.56	4.35	7.77	8.54	8.16	5.96	6.55	6.25	2.57	2.81	2.23
	50	6.59	7.27	6.93	10.80	11.41	11.11	8.70	9.34	9.02	2.98	2.93	2.44
	100	8.52	9.53	9.03	11.17	11.23	11.20	9.85	10.38	10.11	1.87	1.20	1.32
	Mean	6.42	7.12	6.77	9.91	10.39	10.15	8.17	8.76	8.46	2.47	2.31	1.99
Mean N	0	4.60	4.62	4.61	8.05	8.38	8.21	6.32	6.50	6.41	2.44	2.66	2.09
	50	7.07	7.06	7.06	10.80	11.01	10.91	8.94	9.03	8.98	2.64	2.79	2.22
	100	9.09	9.08	9.08	11.00	10.99	11.00	10.05	10.04	10.04	1.35	1.35	1.10
LSD (All, t ha^{-1}		1.16 (*P*=0.0001)	0.94 (*P*=0.0001)		0.79 (*P*=0.0001)	0.67 (*P*=0.0001)							
LSD (Cover t ha^{-1})		0.26 (*P*=0.0001)			0.26 (*P*=0.05)								
LSD (N t ha^{-1})		0.32 (*P*=0.0001)			0.32 (*P*=0.0001)								
CV(%)		11.6	9.4		5.5	4.6							

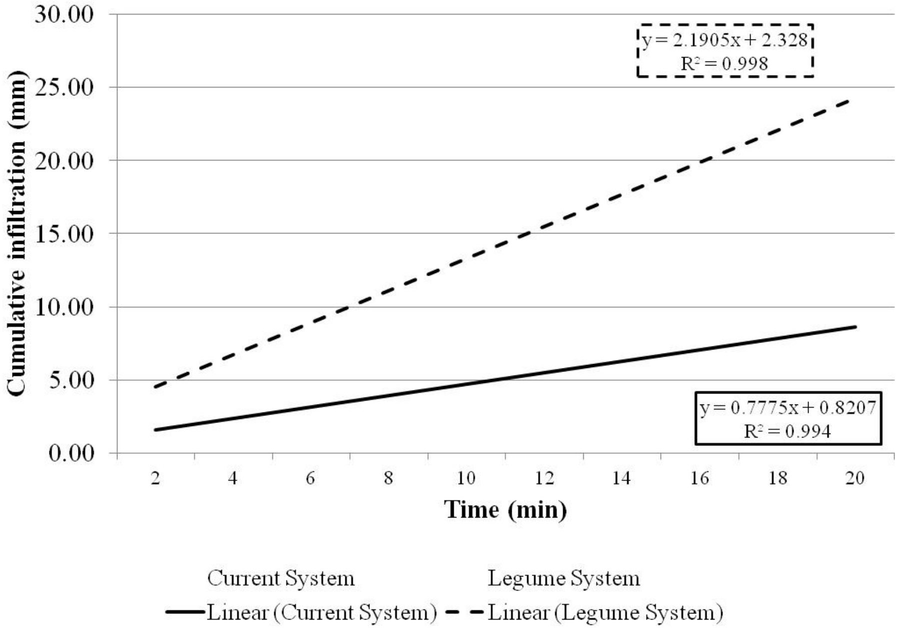

Fig. 1. The effect of cover crop treatment on water infiltration rates comparing a standard practice (no cover crop) to clover bi-crop cover crop system (mm min^{-1}) in 2012.

Table 4. *The yield response in winter wheat (t ha^{-1}) above 'standard practice' in the New Farming Systems 'rotation' study in 2010 and 2012*

Yield (t ha^{-1})		2010			2012			Mean		
	% N Dose	Spring	Mixed	Mean	Spring	Mixed	Mean	Spring	Mixed	Mean
Bi-crop	0	0.90	1.70	1.30	1.22	1.55	1.39	1.06	1.63	1.35
	50	0.71	0.62	0.66	0.37	-0.12	0.12	0.54	0.25	0.39
	100	0.53	0.00	0.26	0.11	-0.08	0.01	0.32	-0.04	0.14
	Mean	0.71	0.78	0.75	0.57	0.45	0.51	0.64	0.62	0.63
Radish	0	0.26	-0.04	0.11	0.67	-0.37	0.15	0.47	-0.21	0.13
	50	0.54	-0.06	0.24	0.45	-0.19	0.13	0.50	-0.13	0.19
	100	-0.11	-0.07	-0.09	0.15	-0.03	0.06	0.02	-0.05	-0.01
	Mean	0.23	-0.05	0.09	0.43	-0.19	0.12	0.33	-0.12	0.11
Legume mix	0	-0.22	0.47	0.12	0.26	0.61	0.44	0.02	0.54	0.28
	50	-0.22	0.47	0.12	0.27	0.43	0.35	0.03	0.45	0.24
	100	-0.62	0.58	-0.02	0.31	0.28	0.29	-0.16	0.43	0.13
	Mean	-0.35	0.51	0.08	0.28	0.44	0.36	-0.04	0.48	0.22

Discussion

'Rotations' experiment

The increased moisture infiltration rates recorded in 2012 with the clover bi-crop systems, depicted in Fig. 1, are analogous to those recorded in 2010; 0.50 mm min^{-1} min (standard practice) to 1.17 mm min^{-1} (clover bi-crop system) (Stobart & Morris, 2011). It is likely these changes relate to the development of a more open soil structure associated with the use of the clover bi-crop. Bulk

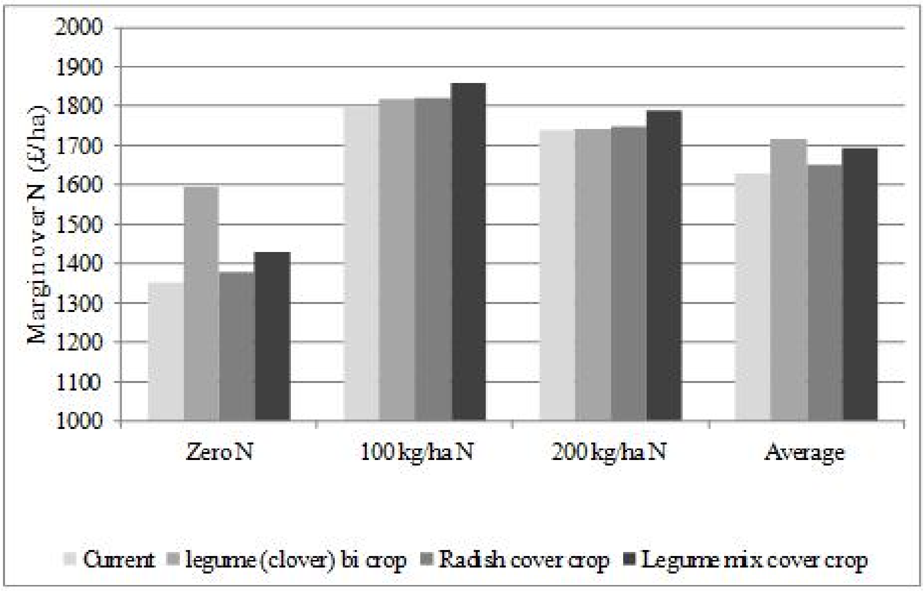

Fig. 2. Margin over nitrogen costs for all cover crop rotations 2012. Based on spot prices at the time of production of £175't for winter wheat and £0.85 kg N.

Table 5. *Winter wheat yields in the NFS cultivations experiment from 2008, 2010 and 2012 (t ha^{-1})*

	Cultivation			Rotation
2008 Yield (t ha^{-1})				
	No cover crop	Cover crop		Mean
Plough	12.93	12.57	No Cover	12.59
Managed	12.41	12.33	Cover crop	12.40
Shallow	12.37	12.22		
Deep	12.63	12.46		
LSD (t ha^{-1})	0.61 (NS, *P*=0.37)			0.30 (NS, *P*=0.20)
CV (%)	3.3			
2010 Yield (t ha^{-1})				
	No cover crop	Cover crop		Mean (all)
Plough	8.34	8.18	No Cover	7.94
Managed	7.90	7.49	Cover crop	7.83
Shallow	7.45	7.39		
Deep	8.08	8.25		
LSD (t ha^{-1})	1.09 (NS, *P*=0.39)			0.55 (NS, *P*=0.66)
CV (%)	9.4			
2012 Yield (t ha^{-1})				
	No cover crop	Cover crop		Mean (all)
Plough	10.45	10.36	No Cover	10.43
Managed	10.40	10.43	Cover crop	10.49
Shallow	10.33	10.63		
Deep	10.54	10.53		
LSD (t ha^{-1})	0.30 (NS, *P*=0.47)			0.15 (NS, *P*=0.41)
CV (%)	2.0			

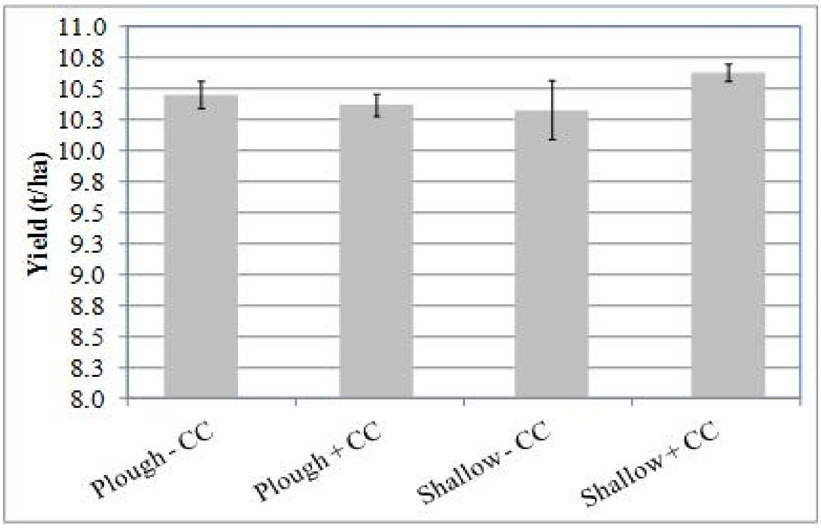

Fig. 3. The impact of cultivation system and cover crop (fodder radish) use (+ CC with cover crop and - CC without cover crop) on yield in winter wheat in plough and shallow tillage based systems in 2012 (t ha^{-1}). Error bars indicate ± the standard error of the mean.

Table 6. *Winter wheat margins in the NFS cultivations experiment from 2012 (£ ha^{-1}). Based on spot prices at the time of production of £175 t^{-1} for winter wheat and £0.85 kg^{-1} N*

	- CC £ ha^{-1}	+ CC £ ha^{-1}
Plough	1210	1194
Deep non-inversion	1279	1278
Shallow non-inversion	1256	1308
Managed approach	1255	1260

density in 2010 indicted associated reductions from 1.17 g cm^{-3} (standard practice) to 1.04 g cm^{-3} (clover bi-crop system) at depths of 20cm which were beneath the level of cultivation (Stobart & Morris, 2011). In addition to generating a more open soil structure for root development these higher infiltration rates would facilitate associated reductions in surface run off and consequently could help to reduce soil erosion, nutrient loss and diffuse pollution risk (Reeves, 1994). The use of cover cropping approaches, regardless of whether they are legume or non-legume based, would also be expected to reduce nitrate leaching (Reeves, 1994; Meisinger *et al*., 1991).

When considering all the cover crop approaches the highest mean yield response over standard practice (as set out in Tables 3 and 4) was associated with the clover bi-crop approach. This is potentially linked to both the changes in soil characteristics within the system and the N provision afforded to the crop from this leguminous bi-cropping approach. However, the yield response from the clover bi-crop approach in 2010 and 2012 was somewhat variable between seasons (possibly related to other seasonal factors influencing N availability and uptake) and in both seasons there was a clear interaction between applied N dose in the wheat and the yield benefit delivered from the cover crop; that is yield response declined with increasing N dose in this system. The yield response averaged across N doses in both 2010 and 2012 for the other cover cropping approaches shows that the fodder radish approach resulted in positive yield responses in two out of four occasions and the legume mix approach in three out of four occasions. Mean cover crop yield responses, averaged across the two rotations, of 0.0–0.2 t ha^{-1} (radish) and 0.1–0.3 t ha^{-1} (legume mix) were noted over the two seasons, depending on N regime.

Considering the yield response averaged across both seasons over the three N doses for the fodder radish and legume mix approaches suggests a similar trend to that seen with the clover bi-crop approach; that is a drop in yield response as the N dose increases. However, the data also suggests differences between the three approaches;

- Clover bi-crop: the largest response at zero N but the response was reduced quite markedly at higher N doses.
- Fodder radish: the smallest mean yield response at each N dose for the cover crop approaches examined.
- Legume mix: greater yield response than the radish approach and mean responses relatively consistent irrespective of N dose.

This potentially suggests differences between the systems in the way in which the cover crops are influencing the soil structure and function for the performance of the wheat crop. However, the exact mechanisms are not clear and it should be noted this data is based on 2 cropping years, further data would be beneficial to examine these trends further.

The standard deviation of the NFS wheat yields from this data are also set out in Table 3. This is also based on limited data so should be treated with some caution; however the standard deviations are similar for each of the system and cover cropping approaches. This is, based on available data, indicative of similar variation in wheat yield with respect to specific approach.

'Cultivations' experiment

Results in winter wheat in 2008, 2010 and 2012 outlined in Table 5 suggest that there is little difference in the range of wheat yields achieved with or without the use of the cover crop.

When comparing within cover cropping strategy across the 3 years the shallow tillage approach has resulted in the lowest yield (*cf.* other cultivation approaches) on five occasions: that is there was only one of the six shallow tillage ± cover crop approaches that was not the lowest yielding within a given 'cover crop x year' combination of tillage approaches. Interestingly, this was the 'shallow tillage + cover crop' rotation in Year 5 (the second rotational cycle with the cover crop) which was the highest yielding treatment in Year 5.

While there was some suggestion of a difference in response pattern between the two approaches (a slight yield loss where cover crops were used in the plough based rotation and a slight yield response where cover crops were used with the shallow non-inversion approach) the differences were small and further seasons of data would be required for a more effective comparison of any responses developing over time.

Cover crops in systems

Research within the New Farming Systems programme is demonstrating clearly that cover crops can make a difference to soil quality and crop yield. However, findings also indicate that interactions are apparent between cover crop choice and farming systems which impact on the end result achieved.

In the 'rotations study' at a 'standard N' regime (similar to current farm practice) the strongest responses were associated with legume mix based cover crop; demonstrating increases in yield and margin over N of 0.3 t ha^{-1} and £51ha^{-1} at 200 kg ha^{-1} N applied N dose in 2012 as shown in Fig. 2. There was a clear interaction between cover crop choice and with N regime apparent in this study, but the 'legume mix' approach tended to give positive yield responses regardless of the approach. In the 'cultivations study' differences in margin were seen from the use of deep rooting brassica cover crops in winter wheat in 2012. The specific margin difference depends on the comparison, but compared to ploughing (the establishment method used for *c*. 60% of current UK wheat crops; Knight *et al*., 2013) the use of shallow tillage and cover crops improved margin by around £98/ha; although it is worth noting that these impacts only became evident following the 2nd cover crop cycle. Further demonstration of this difference in future seasons is needed.

The cost of cover crop system varies with cover crop choice and production technique, but establishment cost of around £20/ha and seed costs in the region of £30–50 ha^{-1} have been reported from the New Farming Systems studies (Stobart & Morris, 2013). The returns recorded in these

NFS studies are similar to these implementation costs. In order to deliver useful financial benefit to farmers the durability and consistency of these responses across the rotation needs further quantification. In addition the impact of the specific cover crop choice, and the interaction with management practice, also needs further assessment. The potential additional financial benefits offered through environmental schemes and associated wider benefits to landscape, environment and habitat management also need consideration; payment for delivering these benefits can also help to improve the attraction for cover crops use on farm. Research within the NFS project remains ongoing.

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