Aspects of Applied Biology ***113**, 2011*
Making Crop Rotations Fit for the Future

New Farming Systems Research (NFS) project: long term research seeking to improve the sustainability and resilience of conventional farming systems

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Summary

In the context of rising global food demand, productive farming systems have never been more important. However, in future production scenarios it is likely inputs will become increasingly restricted and energy more expensive. The New Farming Systems (NFS) study (funded by the The Morley Agricultural Foundation (TMAF) and The JC Mann Trust) being carried out at Morley (Norfolk) on a sandy clay loam soil, is re-examining approaches to rotations and inputs. The research aims to reduce the footprint of conventional farming systems, but at the same time improve sustainability, resilience and output. The NFS programme is running a series of large scale, long term, replicated experiments examining three inter-related themes: fertility building, tillage systems and soil amendments. This paper considers aspects of the use of cover cropping (including using clover bi-crops, as well using legume and brassica cover crops ahead of spring sown crops) and soil amendments (green waste compost) within conventional systems. Impacts on system performance, soils, yield and margin are discussed.

Key words: Farming systems, rotation, cultivation, agronomy, margin

Introduction

Farming systems and rotational decisions have never been more important, in light of a future in which inputs will become increasingly restricted and energy more expensive, while at the same time the global demand for food continues to rise. The New Farming Systems (NFS) research programme is a series of long term studies seeking to develop bio-sustainable cropping systems for conventional arable cropping. The programme is funded by The Morley Agricultural Foundation (TMAF) and The JC Mann Trust and is being carried out at Morley (Norfolk) on a sandy clay loam soil. The research programme is currently in year 6 of a 10 year programme. Long term rotation studies are difficult to undertake and are becoming increasingly rare. TMAF and The JC Mann Trust recognise both the practical and strategic importance of long term systems research to the industry.

Research within the NFS programme is seeking to maintain or increase system output while at the same time addressing aspects of improving efficiency, sustainability and resilience within conventional arable cropping systems. Specific experiments are examining three inter-related themes: fertility building techniques, approaches to tillage and the use of soil amendments. The experiments within the NFS programme are fully replicated, large plot studies that use farm scale equipment and techniques. This paper ostensibly considers NFS research on fertility building techniques and soil amendment usage.

Materials and Methods

Rotation experiments in the NFS programme were initiated in autumn 2007. All experiments are based on a complete or incomplete factorial design with four replicates. Within the 'cover crop' experiment the main plot areas are 12 m × 36 m, however each plot is subdivided into three 12 m × 12 m areas to examine nitrogen (N) dose interactions. Within the 'soil amendment' experiment the main plot areas are 6 m × 12 m. Permanent grass pathways on the site allow each plot to be accessed independently. In each plot all assessments and samples are taken from the central areas on the plots. Both experiments use shallow non-inversion establishment techniques; the specific method varies according to season and crop but typically targets a 10–15 cm depth using disc and/or tine based approaches. Specific 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 inputs are consistent with local best practice.

'Cover crop' experiment

The cover crop experiment is an incomplete factorial design with four replicates. The experiment is comprised of three rotational systems, four management systems and three nitrogen regimes. Further detail of the treatments and the design is presented in Table 1; in total the experiment has 10 treatments. All rotations grow wheat every second year, the year between is a break crop.

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

Three rotations:

System	Rotation	Cropping and harvest year 2008 (Yr 1)	2009 (Yr 2)	2010 (Yr 3)	2011 (Yr 4)	Comments
1	Winter break	ww	wosr	ww	wbn	A conventional approach that can be used as a benchmark for current systems.
2	Spring break	ww	sosr	ww	sbn	Spring crop approaches that may help maximise the benefits of autumn cover/ clover systems.
3	(Un) balanced	sw	sosr	ww	wbn	Spring cropping in years 1 and 2 followed by winter cropping.

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

Four management systems:

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

Three nitrogen management regimes:

N doses applied across treatments as a banded dose, i.e. each 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. 0% of standard dose for the crop being grown
ii. 50% standard dose for the crop being grown
iii. 100% standard dose for the crop being grown.

'Soil amendment experiment'

The soil amendment experiment is a factorial design with four replicates. The experiment comprises three rotational systems with and without the annual application of 35 t ha^{-1} of green waste compost (applied in September and surface incorporated). Further detail of the treatments and the design is presented in Table 2; in total the experiment has six treatments.

Cover crop species and management

The brassica cover crop used in both studies was fodder radish (*Raphinus sativus*). In the 'cover crop' study the legume species mixture was an 'All Species Mixture (ASM)' developed within Defra Sustainable Arable LINK project (LK09106 - Using legume-based mixtures to enhance the nitrogen use efficiency and economic viability of cropping systems); details of this mixture and research can be found in Döring *et al*. (2012) and Storkey *et al*. (2012). 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 'cover crop' study was a small leaf white clover (cv. AberPearl); this was sown is August 2007 and allowed to regenerate naturally each season; input to the bi-cropping system have otherwise been as the 'current practice' system.

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

	Rotational	Compost	Cropping and harvest year			
			2008 (Year 1)	2009 (Year 2)	2010 (Year 3)	2011 (Year 4)
1	Spring breaks	No compost	ww	sosr	ww	sbn
2	Spring breaks + brassica cover crop	No compost	ww	sosr	ww	sbn
3	Continuous wheat	No compost	ww	ww	ww	ww
4	Spring breaks	Compost at 35 t ha^{-1}	ww	sosr	ww	sbn
5	Spring breaks + brassica cover crop	Compost at 35 t ha^{-1}	ww	sosr	ww	sbn
6	Continuous wheat	Compost at 35 t ha^{-1}	ww	ww	ww	ww

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

Results

'Cover crop experiment'

Long term average yield responses over project years 1–4 are presented in Table 3. Yields are presented as a percentage of the mean yield for each season and averaged across all seasons. In both the standard N input scenario and when averaged across all N input regimes, the current practice winter cropping approach gave the highest yields.

The use of clover bi-crops has resulted in notable improvements in soil characteristics compared to current practice. Assessment of bulk density in cropping year 3 (2010 – winter wheat) indicated bulk density reductions from 1.17 g cm^{-3} to around 1.04 g cm^{-3} at depths of 20 cm, this was associated with improvements in water infiltration rates (measured over a 20 minute period using a Minidisc Infiltrometer; Decagon Devices Inc.) from 0.50 mm min^{-1} to 1.17 mm min^{-1}. Marked improvements in crop yield were also noted with respect to the inclusion of a clover bi-crop in 2010. Yield responses and associated impacts on margin over N cost are presented in Table 4 and Fig. 1 respectively. While responses were apparent at all N doses there was clear evidence of a decline in response as N dose increased (with an associated reduction in clover ground cover in

Table 3. *Long term average yield responses over project years 1−4 of the cover crop experiment within the NFS programme*

Rotation and system	Relative yield return			
	Zero N	50% N	100% N	Average
Winter breaks (current)	78	106	147	110
Winter breaks (clover bi crop)	81	115	129	108
Spring breaks (current)	73	103	119	99
Spring breaks (clover bi crop)	73	103	125	100
Unbalanced (current)	71	93	116	93
Unbalanced (clover bi crop)	64	86	99	83
Spring break (brassica cover crop)	81	105	117	101
Unbalanced (brassica cover crop)	73	109	130	104
Spring break (legume mixture cover crop)	80	105	129	105
Unbalanced (legume mixture cover crop)	76	97	116	96

Yields are presented as a percentage of the mean yield for each season and averaged across all seasons.

response to increasing N dose). The average yield response over all N doses from a clover bi-crop was around 8%. Considering the wider rotational response, data for the clover bi-crop for the spring and unbalanced rotational approaches, averaged over a break crop (spring oilseed rape in year 2 – 2009) and winter wheat (year 3 – 2010) cycle, are presented in Table 5. Yields are presented as a percentage of the mean yield for each season and averaged across both seasons.

Table 4. *Yield responses from NFS 'cover crop' experiment in 2010 in winter wheat. Comparing current practice to the inclusion of a white clover bi-crop with three nitrogen (N) regimes (full N dose was 200 kg ha^{-1} N)*

Yield (t ha^{-1})	Zero N	50% N	100% N	Average
Winter breaks (current)	5.00	7.42	9.70	7.37
Winter breaks (clover bi-crop)	5.42	7.80	9.96	7.73
Spring breaks (current)	4.36	6.81	9.14	6.77
Spring breaks (clover bi-crop)	5.26	7.52	9.67	7.48
Unbalanced (current)	4.09	6.80	8.95	6.61
Unbalanced (clover bi-crop)	5.79	7.42	8.95	7.39
Average (current)	*4.48*	*7.01*	*9.26*	*6.92*
Average (clover bi-crop)	*5.49*	*7.58*	*9.53*	*7.53*
% yield increase	*18*	*8*	*3*	*8*
LSD (t ha^{-1})	0.79	1.02	1.18	
CV (%)	11.64	9.77	8.69	
Sig	$P \leq 0.001$	NS ($P = 0.27$)	NS ($P = 0.40$)	

Note - Analyses are presented for the individual fertiliser dose regimes. When all regimes are analysed collectively an LSD of 1.03 t ha^{-1}, a CV of 10.7% and a significance of $P < 0.0001$ were applicable.

Yield and margin data follow a similar pattern to that seen in the wheat crop in 2010 and cumulative margin over N data for the average responses presented in Table 5 are depicted in Fig. 2. Cumulatively, over both the wheat crop and the spring oilseed rape crop, the clover bi-crop improved margin by on average £84 ha^{-1}, although again the response varied in relation to N dose.

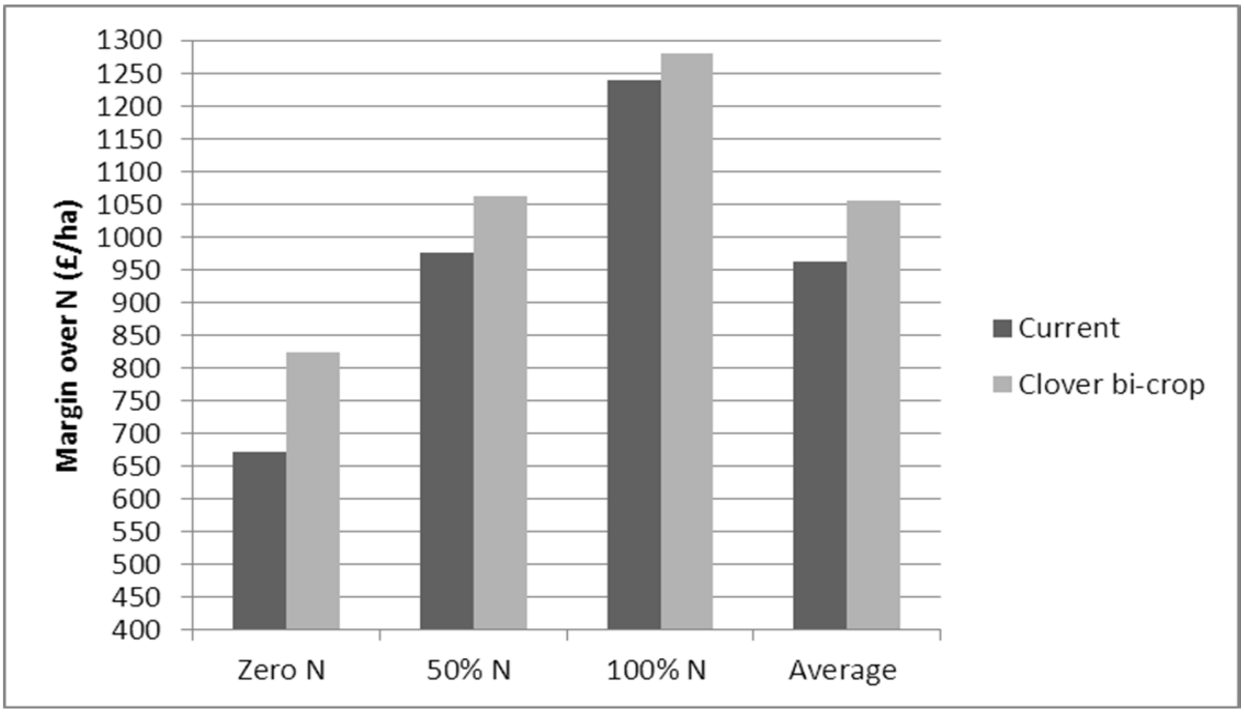

Fig. 1. Margin over nitrogen (N) response in winter wheat comparing current practice to the inclusion of a white clover bi-crop. Data from NFS 'cover crop' experiment 2010. Based on £150 t^{-1} for winter wheat and £0.75 kg N.

Table 5. *Yield response data averaged over a break crop (spring oilseed rape in year 2 – 2009) and winter wheat (year 3 – 2010) cycle*

Rotation and system	Relative yield return			
	Zero N	50% N	100% N	Average
Spring breaks (current)	59	97	119	92
Spring breaks (clover bi crop)	67	98	134	100
Spring break (brassica cover crop)	68	103	122	98
Spring break (legume mixture cover crop)	66	104	129	99
Unbalanced (current)	61	99	128	96
Unbalanced (clover bi crop)	65	99	114	92
Unbalanced (brassica cover crop)	64	110	136	104
Unbalanced (legume mixture cover crop)	73	112	132	106
Average (current)	60	98	124	94
Average (clover bi crop)	66	98	124	96
Average (brassica cover crop)	66	107	129	101
Average (legume mixture cover crop)	70	108	130	103

Yields are presented as a percentage of the mean yield for each season and averaged across both seasons.

The brassica cover crop and legume mix cover crop were also included in each of the spring and unbalanced rotational approaches and yield data are also presented in Table 5. Yield responsesabove current standard practice were apparent for both spring sown cover cropping approaches. The highest average yield response (around 9%) was associated with the legume species mix cover cropping approach. Incremental N doses appeared to have less of an influence on the yield responses for the legume species mix and the fodder radish cover crop approaches compared to that observed with the clover bi-crop. However, the marked improvements in soil

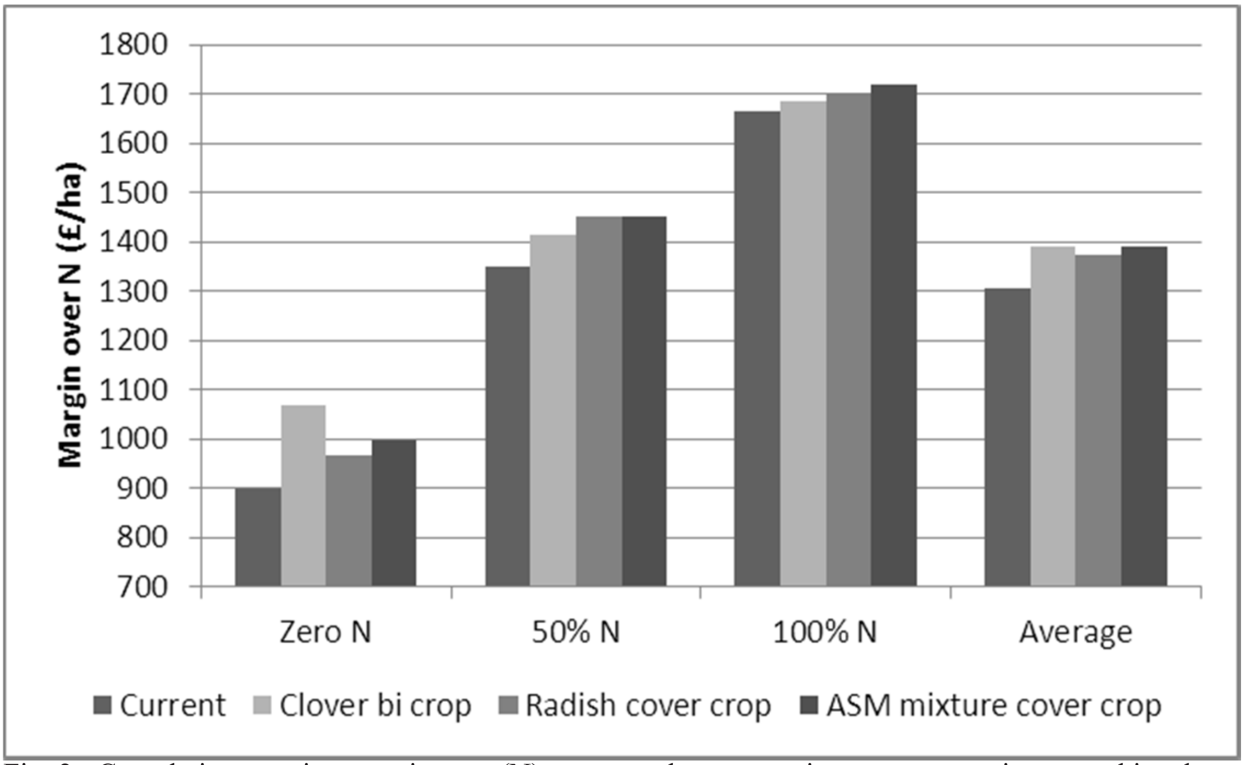

Fig. 2. Cumulative margin over nitrogen (N) response data comparing current practice to a white clover bi-crop, a brassica cover crop or a legume mixture cover crop. Responses were recorded over a break crop (spring oilseed rape in year 2 – 2009) and winter wheat (year 3 – 2010) cycle. Based on £150 t^{-1} for winter wheat, £375 t^{-1} for oilseed rape and £0.75 kg N.

bulk density and water infiltration rates recorded with the clover bi-crop approach were not apparent with the legume species mix and the fodder radish cover crop systems. Associated impacts on cumulative margin over N across both wheat and spring oilseed rape crops are presented in Fig. 2; again all cover crop systems improved margin over N compared to standard practice, with an average improvement of around £77 ha^{-1}. These responses excluded the cost of the cover crop establishment.

'Soil amendment experiment'

Improvements to soil characteristics have been noted following the use of green waste compost over years 1–4 of the soil amendment experiment; specifically, increases in soil nutrient and organic matter levels (Table 6) with associated improvements in water infiltration rates from

Table 6. *Soil nutrient, pH and organic matter (OM) levels in the no compost plots determined in spring 2011 compared with treatments with those receiving an annual addition of 35 t ha^{-1} of green waste compost over the previous 4 year period*

	No compost	Compost
pH	7.4	7.8
Available N (kg ha^{-1})	31.7	39.6
P (mg L^{-1})	21.5	29.3
K (mg L^{-1})	118.3	196.8
Mg (mg L^{-1})	59.2	75.6
OM % (0−10 cm)	1.7	2.4
OM % (20 cm)	2.0	1.9

0.91 mm min^{-1} to 1.17 mm min^{-1} (based on field assessments completed in March 2010). Yield comparisons from the continuous winter wheat rotation with and without the use of green waste compost are presented in Table 7. Wheat crop rotational situations progress from first to fourth wheat crops across this series. While some seasonal variation has been apparent an average yield response to the use of green waste compost of around 7%, has been recorded; with significant yield responses in two of the four seasons (and positive yield responses in three of the four seasons). Yield responses from the other rotational programmes in this experiment have not been included for brevity; however responses to the use of green waste compost have in general been positive.

Table 7. *Yield responses in the soil amendment study from the continuous winter wheat rotation with and without the application of green waste compost*

Season	WW – no compost	WW – with compost	LSD
2007/08	100% (11.99 t ha^{-1})	105%	3.8
2008/09	100% (7.40 t ha^{-1})	93%	16.6
2009/10	100% (6.95 t ha^{-1})	106%	6.8
2010/11	100% (3.96 t ha^{-1})	125%	17.9
Average	100% (7.58 t ha^{-1})	107%	

Benefit of compost compared to plots receiving no compost in each season presented as percentage yield response.

Discussion

While positive benefits from the use of cover crops and soil amendment approaches are apparent in both NFS studies presented in this paper, it should be stressed that long term rotation experiments take several seasons for the systems to become embedded. Given this, while these positive benefits are encouraging, they should be treated with some caution and further development and quantification of the systems over coming seasons would seem prudent.

With regard to the 'cover crop' experiment, while yield responses to the use of cover crops were positive, differences in responses between cover cropping approaches were also apparent. Considering benefits to soil systems, the clover bi-crop approach resulted in notable reductions in soil bulk density and improvements in water infiltration rates. This did not become apparent until cropping year 3 (2010 harvest) and may have been associated with changes to the root structure or development of the clover during this time. It seems probable that the yield responses in the wheat crop recorded in 2010 may have been partly associated with the N fixation in the clover and partly with soil conditioning effects. While yield responses were apparent in response to the other cover cropping approaches, associated improvements in soil structure and water infiltration were not recorded. However, the cover crops in the other approaches have only been imposed periodically (only ahead of spring crops) and perhaps further cycles of cover cropping are needed before effects become apparent and/or can be detected by the assessment methods used.

The positive impacts from the use of cover crops, however, is promising and suggests that such systems may have a role to play in developing bio-sustainable conventional arable cropping practices. The variation observed in soil and yield responses between approaches, however, suggests the need for more research to improve the consistency and resilience of performance and to understand better which approaches are more likely to deliver benefits (or result in problems) in particular scenarios. For example, considering the selection of cover crop species, the brassica species are relatively easy to establish, but can result in volunteer and potentially disease problems in following crops. Alternatively, legume species tend to be more difficult to establish and are generally slower growing. Better understanding of species selection and the development of suitable species mixtures for specific scenarios could improve both performance and accessibility of cover cropping approaches. The cumulative margins over standard practice across the wheat and spring oilseed rape crops for the cover cropping approaches averaged around £80 ha^{-1}; around £84 ha^{-1} for the clover bi-crop and the legume mix cover crop and around £69 ha^{-1} for the brassica cover crop. However, margin over N responses in relation to the clover bi-crop varied markedly in relation to N dose, with greater margin over N apparent at lower N doses. Figures from Stobart & Morris (2011) indicated that the costs associated with delivering a cover crop would be in keeping with these figures. While improvements to techniques and species selection should reduce the costs associated with delivering a cover crop, it is likely that cover crops would only cover their cost based on these margins. However, it should be remembered for all cover cropping systems under consideration benefits may accrue as the systems mature, the choice of specific cover crop species (or species mixtures) should help to maximise any potential benefits, changes to input costs (e.g. fertiliser and fuel) are likely to impact on the return and additional income from appropriate environmental schemes could improve the attraction and add further financial support.

Considering the soil amendment experiment, the use of green waste compost at an annual inclusion of 35 t ha^{-1} has resulted in notable improvements in soil nutrient levels and water infiltration rates and delivered yield improvements of around 7% in winter wheat (0.5 t ha^{-1}). Of specific interest are the improvements in phosphate (P) levels, particularly due to the increasing cost and availability issues associated with P; the value of the P increase alone is estimated to be £108 ha^{-1} (based on March 2010 triple superphosphate fertiliser prices). Improvements in organic matter (OM) are also of interest, although their value is more difficult to quantify. However, increases in OM are associated with improvements in soil cohesion and structure and a strong relationship with the improved water infiltration rates recorded is likely. While the positive benefits of green waste compost are apparent, farm usage tends to be concentrated in areas local to the site of production due to issues of financial viability.

Conclusion

The NFS programme is already demonstrating the potential for cover crops and amendments to deliver improvement to both soil systems and yields. However, it should be noted that while these positive benefits represent encouraging steps to developing increasingly bio-sustainable and resilient rotation systems for conventional cropping, further development, assessment and refinement of the approaches is still required. Going forward it is important that long term systems studies continue to consider the rotation as a whole. Systems research provides an invaluable facility to showcase, demonstrate and evaluate new ideas. This in turn facilitates to the production of impartial information to better enable growers to make informed decisions regarding best practice within their farming systems.

Acknowledgements

The New Farming Systems research programme is supported by The Morley Agricultural Foundation (TMAF) and The JC Mann Trust. Thanks and acknowledgements are also extended to David Jones (host farmer) and members of the project advisory committee. Acknowledgement is also extended to all partners involved in the Defra Sustainable Arable LINK project (LK09106 - Using legume-based mixtures to enhance the nitrogen use efficiency and economic viability of cropping systems) in relation to the development and use of the cover crop legume 'all species mixture' (ASM).

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