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# Approaches to cover cropping and the impact on soils and farming systems

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## Summary

The New Farming Systems (NFS) research project is being undertaken at Morley (Norfolk, UK) and is funded by The Morley Agricultural Foundation and The J C Mann Trust. The research is carried out on a sandy loam soil and consists of a series of large scale, long term, replicated experiments. The project aims to explore ways of reducing the footprint of conventional farming systems, but at the same time improving sustainability, stability and output. The systems being evaluated include a range of cover cropping approaches; specifically the use of long term clover bi-crops, as well as brassica and legume mix based cover crops (used ahead of spring sown crops in the rotations). Research within the NFS project has demonstrated improved soil characteristics and positive yield responses associated with the use of cover crops. However, the range of cover cropping options differ in their management requirements and likely end results and the choice of species should be guided by particular circumstances and the desired goal. The research suggests that the incorporation of cover cropping approaches into rotations has the potential to contribute to agricultural production and also to deliver wider benefits to future farming systems.

**Key words**: New farming systems (NFS), cover cropping, soils, farming systems

## Introduction

The New Farming Systems (NFS) research programme is a series of long term, fully replicated, field studies seeking to develop bio-sustainable approaches to conventional arable cropping. The provision of long term rotational research poses many challenges and as such farming systems projects are a rare resource; however they do provide the industry with valuable research platforms. The NFS programme is funded by The Morley Agricultural Foundation (TMAF) and The J C 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 techniques, approaches to tillage and the use of soil amendments (Stobart & Morris, 2011). Within this programme specific experiments are examining a range of approaches to cover cropping and are exploring how such strategies might contribute to improved resilience and performance within arable systems.

## Materials and Methods

The NFS field research programme was initiated in autumn 2007 and experiments consist of large plot studies based on a complete or incomplete factorial design with four replicates. The research programme uses farm scale equipment and techniques and permanent grass pathways on the site allow each plot to be accessed independently.

*'Rotations' experiment*

This experiment is an incomplete factorial design containing three rotational approaches, three nitrogen (N) regimes and four management systems (including brassica and legume based cover cropping systems). The main plot areas are 12 m × 36 m, however each plot is subdivided into three 12 m × 12 m areas to examine N dose interactions. Further detail of the treatments and the design is presented in Table 1; in total the experiment has 10 treatments. The experiment uses a shallow non-inversion establishment technique (the specific method varies according to season and crop but typically targets 15 cm depth using disc and/or tine based approaches). 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.

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

*Three rotations:*

| System | Rotation | Cropping and harvest year 2008 (Year 1) | 2009 (Year 2) | 2010 (Year 3) | 2011 (Year 4) | 2012 (Year 5) | Comments |
|---|---|---|---|---|---|---|---|
| 1 | Winter break | ww | wosr | ww | wbn | ww | A conventional approach that can be used as a benchmark for current systems |
| 2 | Spring break | ww | sosr | ww | sbn | ww | Spring crop approaches that may help maximize the benefits of autumn cover/bi-crop systems |
| 3 | Mixed cropping | sw | sosr | ww | wbn | ww | A mixed rotation with spring and 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; rotations 1–3 run as standard with regard to inputs and husbandry.

b) Legume (clover bi-crop); rotations 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 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.

*'Cultivations' experiment*

This experiment is a factorial design containing four cultivation approaches and each of these approaches is repeated with and without the presence of a brassica cover crop. The main plot areas are 12 m × 36 m. Further detail of the treatments and the design are presented in Table 2; in total the experiment has eight treatments. 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 species and management*

The brassica cover crop used in both studies is fodder radish (*Raphinus sativus*); this cover crop can root deeply and deep rooted crops can potentially deliver useful bio-cultivation (Hamza & Anderson, 2005). In the 'rotations' study the legume species is a wide ranging '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). This mixture contained 12 legume species and was seeking to both improve soil structure and build fertility; further details of the approach can be found in Döring *et al*. (2013). 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 is August 2007 and allowed to naturally regenerate each season); inputs to the bi-cropping system have otherwise been as the 'current practice' system.

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

*Rotational approach:*

| 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).

*Two management approaches:*

a) Current; systems run as standard with regard to fertiliser inputs.
b) Cover crops; as 'current' but with a fodder radish autumn cover crop ahead of spring sown crops.

*Cultivation approaches:*

i. Plough.
ii. Shallow non-inversion (*c*. ≤ 10 cm).
iii. Deep non inversion (*c*. 20 cm).
iv. Managed regime (decision on cultivation regime is based around prevailing conditions and soil measurements).

## Results

*'Rotations' experiment*

With regard to the use of clover bi-crops, this approach resulted in notable improvements in certain soil characteristics compared to current practice. Specifically, assessment of water infiltration rates (Fig. 1) undertaken in spring 2012 (measured over a 20 minute period using a Minidisc Infiltrometer; Decagon Devices Inc.) demonstrated increases in infiltration from 0.78 mm min$^{-1}$ (standard practice) to 2.19 mm min$^{-1}$ (clover bi-crop system).

The use of the clover bi-crop system in winter wheat also resulted yield improvements, particularly where N dose was restricted. These yield trends were analogous to those recorded in 2010 when the rotation was last all in winter wheat (Stobart & Morris, 2011); a summary of the responses over these two seasons are presented in Table 3.

The effects of all of the cover crop approaches, compared to standard practice, in terms of yield and margin over applied N in 2012 are presented in Table 4 and Fig. 2 respectively.

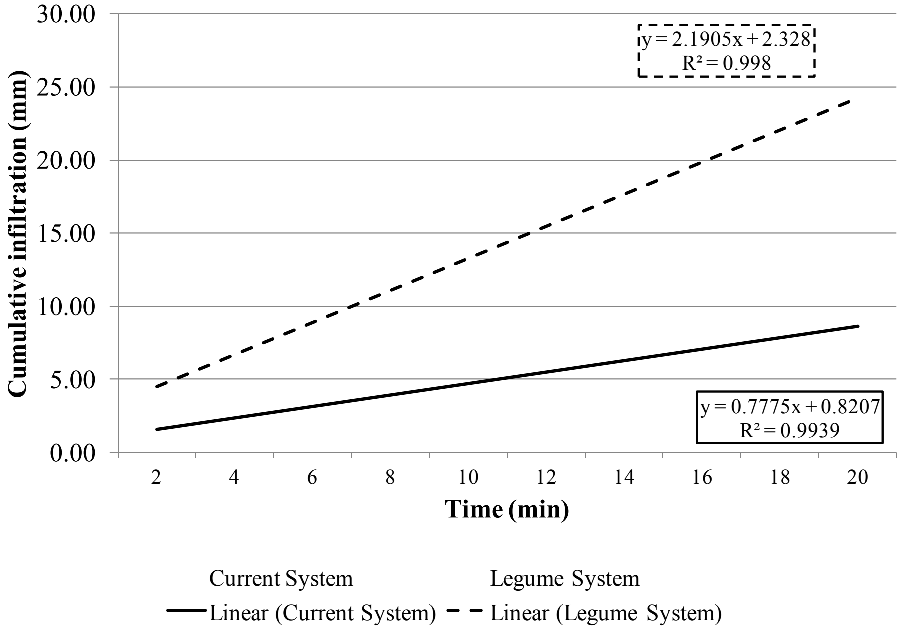


Fig. 1. The effect of cover crop treatment on water infiltration rates (mm) comparing a standard practice (no cover crop) to clover bi-crop cover crop system in spring 2012.

Table 3. *Yield responses from the use of a clover bi-crop cover cropping system compared to standard practice (no cover crop) in winter wheat crops over a range of nitrogen regimes in 2010 and 2012 (t ha$^{-1}$)*

| | No N | Half N Dose | Full N dose |
|---|---|---|---|
| 2010 | | | |
| No cover crop | 4.48 | 7.01 | 9.26 |
| Cover Crop | 5.49 | 7.58 | 9.53 |
| *Yield increase from cover crop* | *1.01* | *0.57* | *0.27* |
| 2012 | | | |
| No cover crop | 7.79 | 10.78 | 10.91 |
| Cover Crop | 8.95 | 10.97 | 10.94 |
| *Yield increase from cover crop* | *1.16* | *0.19* | *0.03* |
| Mean (over two seasons) | | | |
| No cover crop | 6.13 | 8.90 | 10.09 |
| Cover Crop | 7.22 | 9.28 | 10.24 |
| *Yield increase from cover crop* | *1.09* | *0.38* | *0.15* |

*'Cultivations' experiment*

The effect of cultivation practice and cover crop inclusion in the rotation on yield and margin over input and direct machinery costs from 2012 are presented in Table 5. Fig. 3 depicts the plough and shallow tillage treatments yields in the presence and absence of a cover crop with the standard error of the mean (SEM) for each treatment.

Table 4. *Yield responses (t ha$^{-1}$) from NFS 'rotations' experiment in 2012 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 | Half N dose | Full N dose | Average |
|---|---|---|---|---|
| Winter breaks (current) | 7.79 | 10.78 | 10.91 | 9.83 |
| Winter breaks (clover bi crop) | 8.95 | 10.97 | 10.94 | 10.29 |
| Spring breaks (current) | 7.51 | 10.53 | 10.86 | 9.63 |
| Spring breaks (clover bi crop) | 8.73 | 10.90 | 10.97 | 10.20 |
| Spring break (radish cover crop) | 8.18 | 10.98 | 11.01 | 10.06 |
| Spring break (legume mix cover crop) | 7.77 | 10.80 | 11.17 | 9.91 |
| Mixed cropping (current) | 7.93 | 10.98 | 10.95 | 9.95 |
| Mixed cropping (clover bi crop) | 9.48 | 10.86 | 10.87 | 10.40 |
| Mixed cropping (radish cover crop) | 7.56 | 10.79 | 10.92 | 9.76 |
| Mixed cropping (legume mix cover crop) | 8.54 | 11.41 | 11.23 | 10.39 |
| *Average (current)* | *7.74* | *10.76* | *10.91* | *9.80* |
| *Average (clover bi-crop)* | *9.05* | *10.91* | *10.93* | *10.30* |
| *Average (radish cover crop)* | *7.87* | *10.89* | *10.97* | *9.91* |
| *Average (legume mix cover crop)* | *8.16* | *11.11* | *11.20* | *10.15* |
| LSD (t ha$^{-1}$) | 0.96 | 0.71 | 0.32 | |
| CV (%) | 8.1 | 4.5 | 2.0 | |

Note - Analyses are presented for the individual fertiliser dose regimes. When all regimes are analysed collectively an LSD of 0.71 t ha$^{-1}$ and a CV of 5.0% should be used.

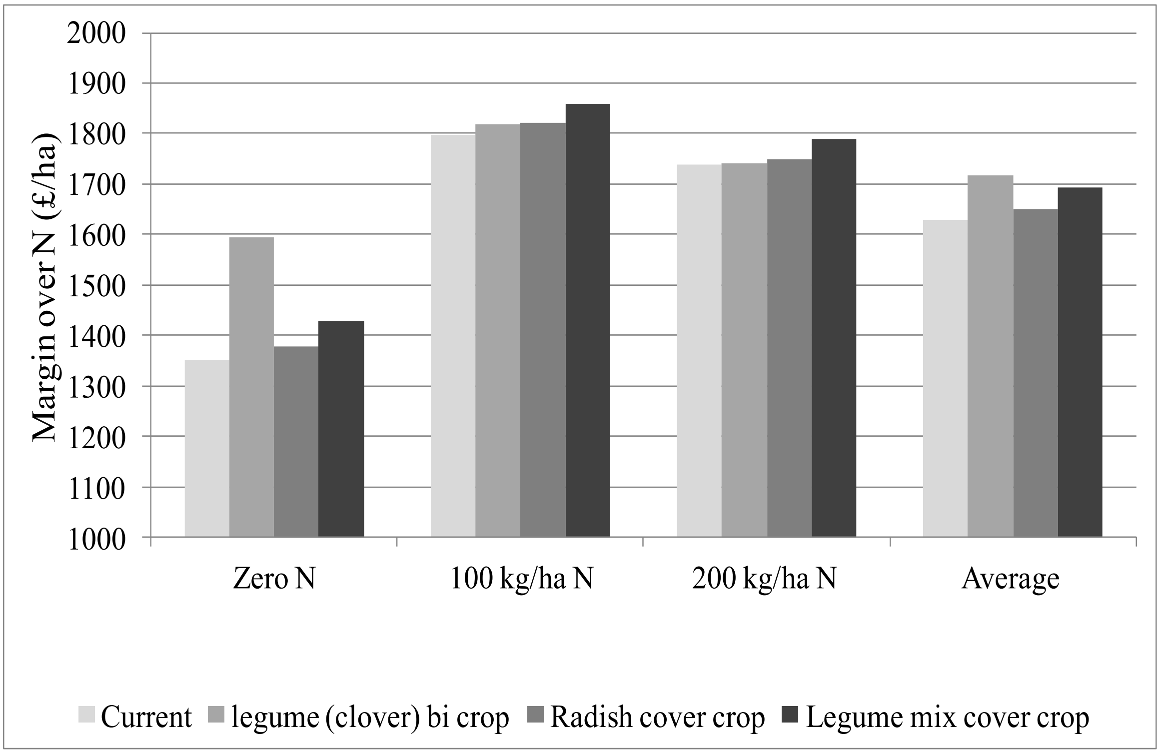


Fig. 2. Margin over nitrogen (N) for winter wheat (£ ha$^{-1}$) 2012 comparing standard practice (no cover crop) to the use of a white clover bi-crop, a brassica cover crop or a legume mixture cover crop across a range of nitrogen regimes (based on £175 t$^{-1}$ for winter wheat, £0.85 kg$^{-1}$ for nitrogen) for the 'Spring breaks' and 'Mixed cropping' rotations.

Table 5. *Yield (t ha$^{-1}$) and margin over input and direct machinery costs (£ ha$^{-1}$) for a range of cultivation and cover crop (fodder radish) use (+ CC with cover crop and – CC without cover crop) systems in winter wheat in 2012. Costs are based on wheat (£175 t$^{-1}$), diesel (£0.68 L$^{-1}$) and fertiliser (£0.85 kg$^{-1}$ for nitrogen)*

| | - CC<br>t ha$^{-1}$ | + CC<br>t ha$^{-1}$ | - CC<br>£ ha$^{-1}$ | + CC<br>£ ha$^{-1}$ |
|---|---|---|---|---|
| Plough | 10.45 | 10.37 | 1210 | 1194 |
| Deep non-inversion | 10.54 | 10.53 | 1279 | 1278 |
| Shallow non-inversion | 10.33 | 10.63 | 1256 | 1308 |
| Managed approach | 10.43 | 10.43 | 1255 | 1260 |
| LSD (t ha$^{-1}$) | 0.30 | | | |
| CV (%) | 1.9% | | | |

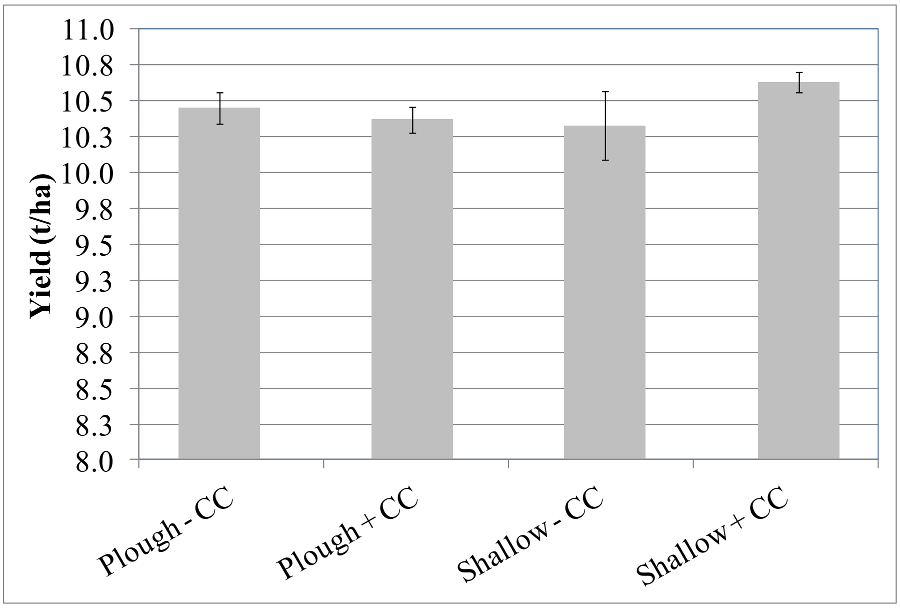


Fig. 3. The impact of cultivation system and cover crop (fodder radish) use (+ CC with cover crop and – CC without cover crop) on yield (t ha$^{-1}$) in winter wheat in plough and shallow tillage based systems in 2102 (t ha$^{-1}$). Error bars indicate ± the standard error of the mean.

**Discussion**

This research presents benefits in terms of both enhanced soil characteristics and positive yield responses associated with the use of cover crops. However, it should be emphasised that there are differences between specific approaches to cover cropping and while these initial findings are encouraging, they should be treated with some caution. Further development and quantification of the systems over coming seasons within these long term studies would be prudent.

With regard to the improvements in infiltration rates recorded in the 'rotations' experiment associated with the clover bi-crop approach, this increase in 2012 from 0.78 mm min$^{-1}$ (standard practice) to 2.19 mm min$^{-1}$ (clover bi-crop system), was in keeping with the increase recorded in the same treatments in 2010, specifically, from 0.50 mm min$^{-1}$ minute (standard practice) to 1.17 mm min$^{-1}$ (clover bi-crop system); in addition in 2010 an assessment of bulk density indicted associated reductions from 1.17 g cm$^{-3}$ (standard practice) to 1.04 g cm$^{-3}$ (clover bi-crop system) at depths of 20 cm (Stobart & Morris, 2011). These improvements in 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). In addition the use of cover cropping approaches, regardless of whether they are legume of non-legume based, would also be expected to reduce nitrate leaching (Reeves, 1994; Meisinger *et al*., 1991).

Considering the yield response from the clover bi-crop approach in 2010 and 2012; the level of response was somewhat variable between seasons. This is possibly related to other seasonal factors influencing N availability and uptake. However, 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. As would be expected the associated financial margin over N benefit obtained in 2012 from the clover bi-crop also diminished as the N dose increases. In addition there was little indication of an appreciable margin over N cost benefit from the use of fodder radish in this experiment in 2012. However, the use of the legume mix cover crop approach (ASM mixture) in the rotation in 2012 did result in a relatively consistent yield benefit, regardless of N regime; resulting in an improvement in margin over N of *c*. £60 ha$^{-1}$ (based on the mean of all N doses). It is worth noting that this figure does not account for the cost of establishing and managing the cover crop in the break crop season.

With regard to the 'cultivations' experiment; the ongoing use of fodder radish in these approaches only demonstrated a clear positive response in the shallow tillage system (tillage restricted to ≤ 10 cm) in 2012. Where the fodder radish wasn't used shallow tillage was the lowest yielding and most variable treatment in the experiment however, where fodder radish was included the treatment was the highest yielding and least variable. Examination of the relevant margin over input costs for these approaches would indicate that the inclusion of fodder radish in the shallow tillage approach increased margin in 2012 by £52 ha$^{-1}$ (comparing shallow tillage ± fodder radish) or £98 ha$^{-1}$ (comparing a plough based approach without the use of cover crops to a shallow tillage based approach using a fodder radish cover crop). The plough based approach remains the most common cultivation method in UK arable systems, with around 60% of farmers establishing wheat using this approach (Knight *et al*., 2012). However, it should be noted that this figure does not include the costs of establishment and management of the radish crop. It is also interesting to speculate why positive responses were recorded from the use of fodder radish in this study but not in the 'rotations' experiment. Further investigation is needed on this issue, however this is possibly associated with the differences in approach to cultivation; in that the only positive responses detected in the 'cultivation' study were associated with the shallow tillage approach (tillage restricted to ≤ 10 cm), while the 'rotations' study employs a cultivation approach targeting a cultivation depth deeper than this. While it is accepted that deep rooting cover crops can deliver bio-cultivation, this may suggest some interaction between the benefits accrued from the use of deep rooted cover crops and the overall approach to cultivation.

With regard to costs of production for cover crops, in this study the establishment cost was around £20 ha$^{-1}$ and while seed costs varied, costs in the region of £30–50 ha$^{-1}$ were representative (depending on the species mix and specific seed rates used). Considered in conjunction with the yield and margin responses achieved, these findings would again suggest the cover cropping approaches used would be likely to result in a similar per hectare implementation cost to the improvement in margin achieved. However, other factors on farm, such as the fit of these cover crops with environmental schemes, will impact on their overall value to the system. In addition, it should be remembered that cover cropping systems responses may accrue and deliver ongoing benefits as the systems mature and specific factors, such as the choice of cover crop species (or species mixtures), changes to input costs (e.g. fertiliser and fuel) and additional income from appropriate support schemes, will all influence the costs and financial benefits delivered.

In conclusion, research within the NFS project has demonstrated improved soil characteristics and positive yield responses benefits associated with the use of cover crops. While 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, it is also clear that there are a range of cover cropping options which differ in their management requirements and likely end results. Given this the approach and choice of species should be guided by particular circumstances, the overall farming system and the desired goal. Further, it should be accepted that the benefits delivered though cover cropping approaches are likely to take time (possibly several runs through the cover cropping cycle) to develop or express fully.


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## References


**Döring T F, Baddeley J A, Brown R, Collins R, Crowley O, Cuttle S, Howlett S A, Jones H E, McCalman H, Measures M, Pearce D B, Pearce H, Roderick S, Stobart R, Storkey J, Tilston E L, Topp K, Watson C, Winkler L R, Wolfe M S. 2013**. Using legume-based mixtures to enhance the nitrogen use efficiency and economic viability of cropping systems. *HGCA Project Report 513*.

**Hamza M A, Anderson W K. 2005**. Soil compaction in cropping systems: A review of the nature, causes and possible solutions. *Soil & Tillage Research* **82**:121–145.

**Knight S, Kightley S, Bingham I, Hoad S, Lang B, Philpott H, Stobart R, Thomas J, Barnes A, Ball B. 2012**. Desk study to evaluate contributory causes of the current 'yield plateau' in wheat and oilseed rape. *HGCA Project Report 502*.

**Meisinger J J, Hargrove W L, Mikkelsen R B, Williams J R, Benson W V. 1991**. Effect of cover crops on groundwater quality. In *Cover Crops for Clean Water*, pp. 57–68. Ed. W L Hargrove. Ankeny, IA: Soil and Water Conservation Society.

**Reeves D W. 1994**. Cover crops and rotations. In *Crops Residue Management*, pp. 125–172. Ed. J L Hatfield and B A Stewart. Advances in Soil Science. Boca Raton, FL: Lewis Publications, CRC Press.

**Stobart R, Morris N L. 2011**. New Farming Systems Research (NFS) project: long term research seeking to improve the sustainability and resilience of conventional farming systems. *Aspects of Applied Biology* **113**, *Making Crop Rotations Fit for the Future*, pp. 67–73.