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The impact of soil management on yield, margin and working practices in long running UK field experiments

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Abstract

Studies on the impacts of sustained soil tillage practice on crop productivity and margin have often been performed on single sites and/or frequently over a limited number of seasons; consequently sites have had insufficient time to develop, restricting the value of comparisons and conclusions. The NIAB led STAR (heavy soil, Suffolk) and New Farm Systems (medium soil, Norfolk) projects, established in 2005 and 2007 respectively, overcome many of these restrictions. Both sites feature fully replicated research on large plots using farm scale equipment and techniques, and utilise contemporary inversion (*c*. 20 cm plough), non-inversion deep (*c*. 20 cm) and shallow (*c*. 10 cm) tillage practices. In both studies rotations are ostensibly based on winter wheat alternating with combinable break crops; the specific choice of break crop differs within and between studies with respect to treatment. Findings from STAR and NFS, considering all crops in the rotation, indicate a numerical reduction in yield when comparing non-inversion to inversion tillage (i.e. considered over all crops ploughing tends to give higher yields). However, considering wheat alone, findings suggest only small percentage yield reductions with shallow tillage (*cf.* plough systems); over seasons, these reductions were not significant at STAR (heavy soil), but were significant at NFS (medium soil). On both sites deep non-inversion tillage tended to give higher margins in wheat and resulted in faster working speeds (*cf.* plough systems); consideration of timelines and speed of working is critical when scaling findings up to farm level.

Key words: Farming systems, management, soils, sustainable, tillage, cultivation, wheat

Introduction

Studies on the impacts of sustained soil tillage practice on crop productivity and margin have often been performed on single sites and/or frequently over a limited number of seasons; consequently sites have had insufficient time to develop, restricting the value of comparisons and conclusions. The NIAB led STAR (Sustainability Trial for Arable Rotations) project in Suffolk and NFS (New Farm Systems) study in Norfolk, established in 2005 and 2007 respectively, overcome many of these restrictions. Both sites feature fully replicated research using contemporary tillage systems on large plots with farm scale equipment. Research is evaluating the impact of long term rotation and tillage practice on soil conditions, system performance and agronomy. This paper focuses on the impact of primary tillage on yields and farm gate economics within the contrasting farming system approaches.

Table 1. *STAR project rotation and cultivation treatments*

Rotation / Year	Cropping 2005/06 (Yr 1)	2006/07 (Yr 2)	2007/08 (Yr 3)	2008/09 (Yr 4)	2009/10 (Yr 5)	2010/11 (Yr 6)	2011/12 (Yr 7)	2012/13 (Yr 8)	2013/14 (Yr 9)	2014/15 (Yr 10)	2015/16 (Yr 11)
Winter cropping	wosr	ww	wbn	ww	wosr	ww	wbn	ww	wosr	ww	wbn
Spring cropping	sbn	ww	so	ww	sbn	ww	sln	ww	so	ww	sbn
Continuous wheat	ww	ww	ww	ww	ww	ww	ww	ww	ww	ww	ww
Alternate fallow	fal	ww	fal	ww	fal	ww	fal	ww	fal	ww	fal

Key: ww (winter wheat), wosr (winter oilseed rape), so (spring oats), sbn (spring bean), wbn (winter bean), sln (spring linseed), fal (fallow).

Cultivation	
Annual plough	Inversion tillage treatment is ploughed every year to *c*. 20–25 cm
Deep tillage	Treatment is cultivated to *c*. 20–25 cm using a non-inversion technique.
Shallow tillage	Treatment is cultivated to *c*. 10 cm using a non-inversion technique.
Managed approach	Decision on cultivation regime is not decided until much nearer the time, decision is based around soil/weather conditions, previous cropping, weed burden, soil assessments etc.

Table 2. *NFS project rotation, cultiation and management treatments*

Rotation	2007/08 (Yr 1)	2008/09 (Yr 2)	2009/10 (Yr 3)	2010/11 (Yr 4)	2011/12 (Yr 5)	2012/13 (Yr 6)	2013/14 (Yr 7)	2014/15 (Yr 8)	2015/16 (Yr 9)
Without cover crop	ww	sosr	ww	sbn	ww	sbr	wosr	ww	so
With cover crop	ww	sosr	ww	sbn	ww	sbr	wosr	ww	so

Key – ww (winter wheat), sosr (spring oilseed rape), wosr (winter oilseed rape), so (spring oats), sbn (spring bean), sbr (spring barley).
Cover crop: radish cover crop autumn sown and destroyed overwinter ahead of spring sown crops.

Cultivation	
Annual plough	Inversion tillage treatment is ploughed every year to *c*. 20–25 cm
Deep tillage	Treatment is cultivated to *c*. 20–25 cm using a non-inversion technique.
Shallow tillage	Treatment is cultivated to *c*. 10 cm using a non-inversion technique.
Managed approach	Decision on cultivation regime is not decided until much nearer the time, decision is based around soil/weather conditions, previous cropping, weed burden, soil assessments etc.

Materials and Methods

The STAR and NFS sites are fully replicated randomised designs using large plots (36 m × 36 m in STAR and 36 m × 12 m in NFS) and farm scale equipment. Both projects have an independent advisory committee, made up of local farmers and agronomists. While soil types differ (STAR - heavy soil, clay loam; and NFS - medium soil, sandy loam) tillage approaches are common to both studies. Within both STAR and NFS projects the plough (inversion to *c*. 20 cm), deep non-inversion (to *c*. 20 cm) and shallow non-inversion (to *c*. 10 cm), are 'consistent systems' and remain the same across seasons. However, the managed approach is a 'variable system' and changes with study season and crop; this decision is based on soil conditions, field assessments, previous cropping, weed burden and local best practice. Both studies use a common cropping approach of ostensibly winter wheat every other year with combinable break crops in intervening seasons. The crop rotation (choice of combinable break crop) varies within and between studies. Crop inputs are based on local best practice (as agreed with the advisory committee) and yields recorded each season with a Sampo plot combine. Treatments are as set out in Tables 1 (STAR) and 2 (NFS); further details can be found in Stobart *et al.* (2014) and Morris *et al.* (2014). Yield data presented are mean data for rotational approaches across all seasons within each study. Cumulative margin data across all seasons within each study are based on a gross output minus direct input and machinery costs for prices relevant to each production season; all crop prices and input costs are determined annually through market bulletin publications and in agreement with the advisory committee.

Results

Long term yield and margin summary data for STAR and NFS are outlined in Table 3. Yields are expressed relative to the plough in each season and the mean figure across seasons is presented. In both STAR and NFS, of the consistent systems, the plough is resulting in the highest yield with a progressive drop off to deep and shallow non-inversion approaches. The managed approach on both sites has resulted in a similar yield to the plough. Cumulative margin results, however, indicate that, of the consistent systems, deep non-inversion tillage results in the highest cumulative margin; although the managed approach again results in a similar cumulative return.

Table 3. *Cross season yield (% of plough) and margin (cumulative £ ha^{-1} and % of plough) with respect to tillage across all crops. STAR harvest years 1–10 and NFS harvest years 1–9*

	Yield relative to ploughed (%)		Cumulative gross margin minus machinery cost (£ ha^{-1})		Margin relative to plough (%)	
	NFS	STAR	NFS	STAR	NFS	STAR
Plough	100	100	4133	4326	100	100
Managed	100	100	4468	4572	108	106
Deep	95	98	4364	4516	106	104
Shallow	89	96	4131	4272	100	99

Within both the STAR and NFS rotations the regular use of winter wheat also allows the impact of tillage on wheat to be evaluated in the context of longer term data sets. Winter wheat yield data for the 'consistent systems' (where treatments have remained the same over this time period) from harvest years 2, 4, 6, 8 and 10 of the STAR project are presented in Table 4; this depicts the mean data for 'all rotations'. Yield differences are significant in two of the five seasons with P values of around 0.1 apparent in two further seasons. Winter wheat yield from the 'consistent systems' (where treatments have remained the same over this time period) in harvest years 1, 3, 5 and 8 of

Table 4. *Yield (t ha^{-1}) and margin (£ ha^{-1}) data for winter wheat and tillage in STAR in years 2 (2006/07), 4 (2008/09), 6 (2010/11), 8 (2012/13) and 10 (2014/15). Cross season analysis for tillage is as presented in the table; 'year' was significant at* P*<0.001 and 'treatment x year' interaction was NS*

	Seasonal yield data (t ha^{-1})						Mean yield and margin data		
Tillage	Year 2	Year 4	Year 6	Year 8	Year 10	Mean yield (t ha^{-1})	Yield (% of plough)	Margin (£ ha^{-1})	Margin (% of plough)
Plough	8.64	8.51	6.83	8.61	11.64	8.85	100	547	100
Deep	7.78	9.00	7.40	8.30	11.69	8.82	100	584	107
Shallow	7.52	8.80	7.32	8.01	11.62	8.66	98	571	104
Mean	7.98	8.77	7.18	8.31	11.65	-			
P value	*P*<0.0001	NS (*P*=0.14)	*P*<0.05	NS (*P*=0.11)	NS	NS			
LSD (t ha^{-1})	0.45	0.42	0.49	0.57	0.24	1.02			

Table 5. *Yield (t ha^{-1}) and margin (£* ha^{-1}*) data for winter wheat and tillage in NFS in years 1 (2007/08), 3 (2009/10) and 5 (2011/12) and 8 (2014/15). Cross season analysis for tillage is as presented in the table; 'year' was significant at* P*<0.001 and 'treatment x year' interaction at* P*<0.01*

	Seasonal yield data (t ha^{-1})					Mean yield and margin data		
Tillage	Year 1	Year 3	Year 5	Year 8	Mean yield (t ha^{-1})	Yield (% of plough)	Margin (£ ha^{-1})	Margin (% of plough)
Plough	12.75	8.26	10.41	10.70	10.53	100	921	100
Deep	12.55	8.17	10.54	11.27	10.63	101	978	106
Shallow	12.30	7.42	10.48	10.45	10.17	96	930	101
Mean	12.53	7.95	10.47	10.81	-			
P value	NS (*P*=0.16)	NS (*P*=0.11)	NS	NS (*P*= 0.10)	*P*<0.001			
LSD (t ha^{-1})	0.30	0.77	0.21	0.68	0.16			

the NFS Cultivations study is presented in Table 5. This shows the mean data for the 'with and without' cover crop rotational approaches. Yield differences presented for individual seasons are not statistically significant, although P values of around 0.1 in three of the four seasons were apparent. In both studies year had a statistically significant impact on yield and cross season differences were statistically significant in NFS but not in STAR.

Discussion

The long running, large scale STAR and NFS farming systems projects provide a platform to determine the impact of tillage and rotational practice on soil condition and ultimately the influence of these parameters on yield, margin and crop performance.

While the impact of tillage practice on yield varied both with season and between STAR and NFS, in general ploughing has tended to result in the highest mean yields across the rotation, with progressive yield loss to deep and shallow non-inversion systems. This drop off was more pronounced on the medium soil type at NFS compared to the heavy soil type in STAR. This is possibly associated with the lighter soils being more prone to loss of structure where some deeper rectification is not applied. Within wider assessment work undertaken in AHDB project 3786 (Platforms to test and demonstrate sustainable soil management: integration of major UK field experiments) on the sites (Hallett *et al*., 2014*a*,*b*) pans have been detected under non-inversion tillage systems (notably in the shallow non-inversion tillage system); these pans were present on both sites and are developed to an extent that could limit root growth and potentially have an impact on yield.

With regard to the impact of system on rotational margins across all crops, despite the high yields associated with the plough based system, of the consistent systems, the deep non-inversion tillage approach has resulted in the highest margins. Interestingly though, in both STAR and NFS the cost saving associated with the shallow non-inversion tillage system compared to the plough based approach tended to balance up; that is, despite the lower yields obtained in the shallow non-inversion tillage system the cumulative margins relative to plough were similar. However, in both studies, the managed approach, using a seasonal decision based on field assessment and crop performance and requirements, has resulted in the highest mean margin. In addition to margin it should also be noted that ploughing would have also resulted in slower speeds of working (*cf*. non-inversion tillage systems); potentially impacting on timeliness of operation over a total farm area. This is potentiality of greater importance than small differences in rotational margin.

While differences in crop rotations between STAR and NFS restrict comparisons for some crop types, the regular use of winter wheat in both studies enables a longer term evaluation of the impact of tillage on the performance of first wheat crops. For both studies, in most individual seasons, the lowest winter wheat yields tended to arise from the use of shallow non-inversion tillage systems. With respect to mean yields across seasons, both STAR and NFS demonstrated similar yields for plough and deep non-inversion systems, but lower wheat yields for shallow non-inversion tillage systems. While 'year' was a statistically significant effect, the cross season differences were a 2% reduction in yield compared to plough based approaches for STAR and a 4% reduction compared to the plough in the NFS study for the shallow non-inversion system; this difference was statistically significant in NFS but not in STAR. Regardless of the statistical significance, findings suggest only small percentage yield reductions with shallow tillage (*cf*. plough systems) indicating that wheat yields are relatively robust with respect to the tillage approaches assessed on these sites. In addition, it should be noted that speed of working and timeliness of operation to ensure good field conditions should also be considered when looking at relatively small differences in yield or margin in winter wheat. With regard to margins, the deep non-inversion treatment resulted in the highest margins in both studies, but in both STAR and NFS shallow and deep non-inversion treatments resulted in greater margins compared to the plough. For deep non-inversion treatments this benefit was 6–7% and for shallow non-inversion treatments gain was 1–4%.

Research in these STAR and NFS projects remain ongoing; this is seeking both to better develop best practice and to identify soil physical indicators for crop productivity that will assist farmers in improving and deploying management practices. Further information on long term best practice with respect to tillage, in both cereal and break crop production, will better enable growers to maximise system potential, resilience and environmental security in our farming systems.

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