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Tillage and cover crop practices – evaluation indicators and metrics

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Summary

Improving soils, resilience and system productivity through the use of cover crops and lower disturbance tillage practices is of increasing interest to the farming community. These goals are very much in keeping with the aspirations of Sustainable Intensification (SI). The Sustainable Intensification Research Platform (SIP) is a highly collaborative programme that has been exploring the risks and opportunities associated with practical delivery of SI at farm and landscape level. The SIP arable study farm at Morley has been evaluating the use of tillage approaches and cover crop practices in a large-plot, fully replicated experiment with additional split-field comparisons for farm-scale evaluation. Metrics indicate the potential for positive yield and financial responses associated with cover crop use in arable systems, but equally that system interactions (e.g. between tillage approach and crop rotation) will affect the outputs and potential benefits achieved.

Key words: Farming systems, tillage, productivity, cover crops, soils

Introduction

There is increasing 'on farm' interest in the use of cover crops to improve productivity and resilience of farming systems, and also for their capacity to provide wider environmental benefits. These goals are very much in keeping with Sustainable Intensification (SI) aspirations. While the term SI can be subjective, the Sustainable Intensification Research Platform (SIP) suggests that key SI objectives in an agricultural context may be expressed as '*managing farmland to increase farm output and competitiveness, whilst protecting the countryside and enhancing environment and social benefits'* (www.siplatform.org.uk). The SIP programme is a highly collaborative platform, working with stakeholders to explore risks and opportunities associated with the practical delivery of SI from a range of perspectives and at different scales. At farm level, the SIP arable study farm at Morley (Norfolk) has examined the impacts of cover crops on aspects of soils, environment and production. This paper focuses on the impact of primary tillage and cover crops on the productivity, profitability and sustainability of an arable cropping system using a number of key metrics and indicators.

Materials and Methods

The research at Morley (on a sandy loam soil) builds on the New Farming Systems (NFS) programme that was initiated in 2007. This has examined the interactions between tillage system (plough inversion; deep non-inversion; or shallow non-inversion) and brassica cover crop inclusion (radish, *Raphinus sativus*) in fully-replicated large-plot experiments that are managed using farm-scale equipment. Rotations alternate mainly between winter wheat and spring-sown combinable crops, in the presence / absence of an autumn-sown cover before spring crops. Treatments are as set out in Table 1 (NFS replicated large-plot work); further details can be found in Stobart *et al*. (2017*a*).

A further study using split fields was established, part of which had an overwinter cover crop (sown with a tine drill in early September) and part of which did not. In all cases the cover crops were destroyed using glyphosate herbicide applied after winter, and were followed by a crop of sugar beet planted in April. The fields were then assessed in the same splits for one or more crop years in order to monitor the residual effects of the cover crops in the rotation. Details of the cover crops and harvest crops grown are shown in Table 2. This paper examines results from a 4-year period (2013/14 – 2016/17) spanning the duration of the SIP study.

The metrics used to assess crop productivity and profitability are yield and margins. In the NFS replicated large-plot study, the yield data are treatment means for rotational approaches across seasons. In the split-field study yields are estimated by extraction from yield maps from a commercial combine using areas of the field in each treatment before the cover crop as control yield for reference, or by hand harvest sampling marked areas of the field where a cover crop had or had not been previously sown. Cumulative margin data across seasons are based on the gross value of the crop output minus direct input and machinery costs, using costs and prices relevant to each production season. Given that the benefits of cover crop inclusion were anticipated to last over more than 1 year, a share of the cumulative cover crop costs (£110 ha^{-1}) is deducted from the cumulative margins for the cover crop rotation treatments. Soil organic matter (SOM) is determined from soil samples (0–20 cm depth) taken from random sampling points within a given treatment and bulked before sending to a commercial lab (NRM Laboratories) for analysis. The metric used for soil structure is the Visual Evaluation of Soil Structure (VESS) from Ball *et al*. (2007). Earthworm numbers and weight are sampled as an indicator of soil biological activity by extracting, counting and weighing the earthworms from a block of soil (measuring approximately 20 cm × 20 cm × 20 cm).

Results

Replicated large-plot study

Crop yield and margin summary data for each system in the NFS over the duration of the SIP study are presented in Table 3. With the exception of year 7 (2013/14, oilseed rape), deep tillage has given the highest yield each season, but with no consistent difference between plough and shallow tillage over seasons. Cumulative yield generally followed a similar trend, with deep tillage resulting in the highest total, although wheat yields tended to mask the oilseed rape yield differences. Cumulative relative yields, calculated as a % of the plough with no cover crop and then averaged over the 4 years, were calculated (where plough with no cover crop = 100). There was little difference between systems but deep tillage tended to result in higher yields. Cumulative margins (less cover crop cost), calculated as a % of the plough with no cover crop, tended to reflect the same trend as yield with the highest cumulative margin associated with the deep tillage irrespective of the use of a cover crop. When comparing system performance in the two seasons where winter wheat was grown (year 8, 2014/15; and year 10, 2016/17), excluding deep tillage in year 8 (where little difference in the use of cover crop was recorded); the inclusion of cover crops resulted in higher yields in all tillage approaches compared to no cover crop, with a mean increase in yield of 0.32 t.

Table 1. *NFS replicated large-plot study rotation, tillage and cover crop 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)	2016/17 (Yr 10)
Without cover crop	ww	sosr	ww	sbn	ww	sbr	wosr	ww	so	ww
With cover crop	ww	sosr	ww	sbn	ww	sbr	wosr	ww	so	ww

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.

Tillage	
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.

Table 2. *Split-field studies on the Morley Study Farm*

	Cover Crops Grown		Harvest Crop Grown		
Field	Year	(Part field)	2014/15	2015/16	2016/17
Manns	2014/15	Black oats (60%) + vetch (40%)	Sugar Beet	Winter Wheat	Winter Barley
Home Close	2015/16	Tillage radish	Winter Wheat	Sugar Beet	Combine Peas
Brockholes	2015/16	Commercial Mix*	Winter Wheat	Sugar Beet	Spring Barley

*Oat, buckwheat, sunflower, Phacelia, false flax, linseed, 'deeptill' radish, white mustard and bristle oat.

Table 3. *Seasonal yield (t ha^{-1}), cumulative yield (t ha^{-1}), relative yield (% of plough, no cover crop) and margin (£ ha^{-1}) data for NFS years within SIP study: years 7 (2013/14) to 10 (2016/17). Total cost associated with cover crop inclusion for the four year period was calculated at £110 ha^{-1}. SEM values presented in brackets*

		Seasonal yield data (t ha^{-1})				Cumulative yield and margin data			
Tillage	Rotation	Year 7 (wosr)	Year 8 (ww)	Year 9 (so)	Year 10 (ww)	Cumulative yield (t ha^{-1})	Yield (% of plough)	Cumulative margin less cover crop cost (£ ha^{-1})	Margin (% of plough)
Plough	No cover crop	3.63 (0.25)	10.61 (0.17)	8.11 (0.08)	10.35 (0.14)	32.70	100	2769	100
	Cover crop	3.30 (0.16)	10.79 (0.41)	8.03 (0.12)	10.89 (0.11)	33.00	99	2649	96
Deep	No cover crop	3.96 (0.11)	11.33 (0.20)	8.22 (0.19)	10.54 (0.14)	34.05	105	3078	111
	Cover crop	3.72 (0.16)	11.22 (0.26)	8.16 (0.13)	10.85 (0.06)	33.94	103	2919	105
Shallow	No cover crop	4.19 (0.10)	10.26 (0.33)	8.12 (0.18)	9.98 (0.20)	32.55	102	2973	107
	Cover crop	4.00 (0.10)	10.65 (0.33)	8.17 (0.14)	10.23 (0.27)	33.04	103	2896	105
Tillage Mean	No cover crop	3.91 (-)	10.73 (-)	8.15 (-)	10.29 (-)	33.10	102	2940	106
	Cover crop	3.67 (-)	10.88 (-)	8.12 (-)	10.65 (-)	33.33	102	2821	102
P value		*P*=0.03	NS *P*=0.33	NS *P*=0.95	NS *P*=0.13	-	-	-	-
LSD (t ha^{-1})		0.521	1.077	0.408	0.751	-	-	-	-

Soil physical and biological indicators (SOM, VESS and worms) in the NFS over the duration of the SIP study are presented in Tables 4 and 5. There is no consistent difference in SOM between the systems with or without the inclusion of cover crops, or between tillage systems (Table 4), but ploughing resulted in the lowest mean SOM content (0–20 cm depth) across years. Soil structure, assessed using the VESS method (Table 5), indicated no consistent differences between tillage or cover crop systems, apart from year 10 (2016/17), when the use of a cover crop in the rotation had improved VESS scores in all tillage systems. There were no statistically significant differences in earthworm counts (Table 5) in any one year. However, in year 9, the only year of the three in which a cover crop was grown, higher counts were recorded in the cover crop rotation.

Table 4. *Summary of SOM (%) content for NFS years 7 (2013/14) to 10 (2016/17)*

		Soil organic matter % – 0–20 cm depth				
Tillage	Rotation	Year 7	Year 8	Year 9	Year 10	Mean
Plough	No cover crop	2.2	2.1	2.4	2.4	2.3
	Cover crop	2.2	2.2	2.3	2.5	2.3
Deep	No cover crop	-	2.1	2.5	2.6	2.4
	Cover crop	-	2.4	2.4	2.5	2.4
Shallow	No cover crop	2.4	2.6	2.5	2.4	2.5
	Cover crop	2.6	2.3	2.3	2.5	2.4
Tillage Mean	No cover crop	2.3	2.2	2.2	2.4	2.3
	Cover crop	2.4	2.3	2.3	2.5	2.4

Table 5. *VESS scores for NFS years 8 (2014/15) to 10 (2016–17) and worm counts for NFS years 7 (2013/14) to 9 (2015–16).* SEM *values presented in brackets.*

		VESS scores			Total worms m^{-2}		
Tillage	Rotation	Year 8	Year 9	Year 10	Year 7	Year 8	Year 9
Plough	No cover crop	2.5 (0.05)	2.6 (0.03)	1.7 (0.36)	556	188	175
	Cover crop	2.8 (0.13)	2.7 (0.04)	1.3 (0.18)	.	106	300
Deep	No cover crop	2.6 (0.02)	2.5 (0.03)	1.6 (0.20)	506	200	.
	Cover crop	2.6 (0.10)	2.6 (0.03)	1.6 (0.14)	.	219	.
Shallow	No cover crop	2.6 (0.09)	2.5 (0.21)	1.8 (0.09)	469	100	217
	Cover crop	2.5 (0.03)	2.5 (0.02)	1.7 (0.18)		75	258
Tillage Mean	No cover crop	2.6	2.6	1.7	510	163	196
	Cover crop	2.6	2.6	1.5	.	133	279
P value		-	-	-	NS *P*=0.75	NS *P*=0.49	NS *P*=0.74
LSD (total m^{-2})		-	-	-	279.3	171.4	284.6

Field-scale study

Crop yield estimates from the field-scale study are shown in Tables 6 (commercial combine yield maps) and 7 (hand harvested). The yield map derived yield estimates (Table 6) show little difference between treatments, with no notable effects of the cover crops on the relative yields of the cover crop and no cover crop areas that could be determined. Hand harvested yields taken from sugar beet (grown directly after the cover crops) and combining peas (sown following the sugar beet e.g. 18 months after the cover crops was sown) indicated a positive yield response following a cover crop in both sugar beet (19% increase) and combining peas (8% increase).

Scores relating to VESS (Table 8) varied between fields and years, but there were no consistent differences between the cover crop and no cover crop treatments. In general (for Manns and Home Close fields), worm populations (Table 8) tended to show more worms in the cover crop than no cover crop areas, but this was not the case for Brockholes field.

Table 6. *Yield (t ha^{-1}) estimates for split-field studies extracted from commercial combine yield maps using area in the field in each treatment before the cover crop (2013/14) as a control yield for reference. SEM values presented in brackets*

Field	Year	Harvest Crop	Yield (t ha^{-1}) No Cover crop	Yield (t ha^{-1}) Cover crop	% of no cover crop area: No cover crop	% of no cover crop area: Cover crop
Manns	2013/14	WW (before cover crop)	12.9 (0.05)	12.7 (0.06)	100	98
	2015/16	WW	10.5 (0.05)	10.2 (0.11)	100	97
Manns	2013/14	WW (before cover crop)	12.7 (0.07)	13.0 (0.08)	100	102
	2016/17	WB	7.9 (0.05)	8.2 (0.07)	100	104
Brockholes	2014/15	WW (before cover crop)	12.8 (0.12)	12.7 (0.10)	100	99
	2016/17	SB	8.2 (0.11)	8.0 (0.14)	100	98

Table 7. *Hand harvested yield (t ha^{-1}) for Home Close split field at Morley. SEM values presented in brackets*

Field	Year	Harvest Crop	Yield (t ha^{-1}) No Cover Crop	Yield (t ha^{-1}) Cover crop	Percent of No cover crop: No cover crop	Percent of No cover crop: Cover Crop
Home Close	2015/16	Sugar Beet	108 (6.43)	129 (4.55)	100	119
	2016/17	Combine Peas	6.35 (-)	6.83 (-)	100	108

Table 8. *Total worm counts (m⁻²) and weight (g m⁻²) and VESS Scores for split fields assessed at Morley. SEM values presented in brackets*

		Total worms (m^{-2})		Total weight ($g\ m^{-2}$)		VESS Score	
Field	Year	Cover crop	No cover crop	Cover crop	No cover crop	Cover crop	No cover crop
Manns	2014/15	175 (50.00)	50 (25.00)	38 (14.50)	6 (3.00)	2.8 (0.05)	2.4 (0.03)
	2015/16	153 (18.37)	142 (27.00)	50 (11.87)	28 (10.22)	2.6 (0.27)	2.5 (0.14)
	2016/17	194 (28.06)	98 (9.88)	51 (17.53)	22 (7.42)	-	-
	Mean	174	97	46	19	2.7	2.4
Home Close	2015/16	541 (155.68)	516 (71.20)	98 (18.84)	142 (48.58)	2.5 (0.04)	2.7 (0.07)
	2016/17	133 (30.05)	84 (8.33)	37 (14.50)	11 (2.80)	1.7 (0.07)	2.0 (0.13)
	Mean	337	300	50	77	2.1	2.3
Brockholes	2015/16	383 (162.23)	600 (137.69)	102 (41.51)	165 (32.59)	2.5 (0.08)	2.6 (0.05)
6 Site Year Mean		263	248	63	62	2.4	2.4

Discussion

With regard to the impact of system on rotational margins across the study period, the deep non-inversion tillage system resulted in the highest margins, which is in keeping with previously reported findings (Stobart *et al*., 2017*a*).

The use of cover crops is of increasing interest to growers to improve soils, resilience and farming systems. Through the SIP study, both the replicated plot and field-scale trials on the Morley arable study farm highlighted the potential benefits that cover crops can have within farming systems. While the impact of cover crops on crop performance, soil physical and biological indicators varied both with season and between crops, the use of cover cropping within a rotation tends to give a small yield increase in winter wheat of around 0.3 t ha^{-1}. Yield increases are not always apparent in the crop immediately after the cover crop but sometimes in the following crop after that. This is possibly associated with improved soil structure as a result of the rooting from the cover crop allowing subsequent crops to better exploit water and nutrients within the soil profile. It is therefore important that growers seek to consider benefits of cover cropping over the full rotation and not just a single crop. However, where the cost of growing a cover crop over the period is taken into account, and despite the trend for increases in winter wheat yield with cover crops, the margins were reduced where cover crops had been grown, irrespective of tillage approach.

Findings from the split-field studies also indicate the potential for cover crops to improve yields in following crops, but a more robust evaluation across multiple fields and years is needed. The studies also suggest that in some instances improvements to soil structure and enhanced soil biology may be achieved, in keeping with wider farm-scale evaluation of cover crops reported by Stobart *et al*. (2017*b*). Cover cropping approaches need further study on a wider scale to include a contrasting range of soil types and cropping systems in order to fully evaluate their benefits over a range of metrics.

There is on-going research in the NFS projects that is seeking to further develop best practice and identify suitable indicators to assist farmers in improving and deploying management practices utilising cover crops. Further information on long-term management of cover crops within farming systems with respect to tillage, in both cereal and break crop production, will better enable growers to maximise system potential, resilience and enhance environmental and social benefits of our farming systems.

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