Sustainability Trial in Arable Rotations (STAR project): a long term farming systems study looking at rotation and cultivation practice

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Summary

The STAR project (Sustainability Trial in Arable Rotations) is a long term rotation study initiated in 2005 at Stanaway Farm, Otley, Suffolk, on a Beccles/Hanslope series soil. The research is funded though the Felix Thornley Cobbold Trust and delivered through NIAB TAG. The trial is fully replicated on large plots using farm scale equipment. The study examines the interaction between four rotation and four cultivation methods. Cultivation techniques are annual ploughing, deep non-inversion, shallow non-inversion and a managed approach. Each rotation includes winter wheat every other year with an intermediate break crop; break crop choice differentiates each rotation. 'Winter cropping' has a winter break crop; 'spring cropping' a spring break crop; 'continuous wheat' grows wheat every year and the 'alternate fallow' alternates between wheat and a mustard cover crop. This paper considers findings in relation to agronomy (including grass weeds), soil parameters, yield and margin. Findings from the STAR project suggest that while ploughing tends to give the highest yields the highest margins are associated with a managed approach.

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

Introduction

Cropping systems are the result of the temporal and spatial arrangements of crops together with the associated management practices. Consequently their design requires consideration at farm level of a range of complex and interacting factors. The overall aim is to optimise profitability by enhancing the productivity of land per unit of input (seed, fertiliser, pesticide, tillage), sustainability must be evaluated over several crop cycles to ensure sustainability of profit and of the resource base. The STAR project (Sustainability Trial in Arable Rotations) was developed both to provide local growers with a practical demonstration that models their own farm situation, and also to generate impartial, statistically valid, quantifiable data that clearly demonstrates the impact of farm decisions on system stability and profitability. Such trials are needed to enable growers to make more informed choices that will be of benefit to their businesses. Data interpretation and key messages from this project come from both direct information (e.g. impacts on soil parameters, grass weeds, diseases and yields) and from derived financial analysis (e.g. gross margins for each scenario).

Materials and Methods

Layout and management

The STAR project is a long term rotational systems study that was initiated in autumn 2005 at Stanaway Farm, Otley, Suffolk on a Beccles/Hanslope Series clay soil. The research is funded though the Felix Thornley Cobbold Trust and delivered through NIAB TAG. The trial is fully replicated on large plots and uses farm scale equipment. The study is examining the interaction between four different rotations and four different cultivation methods. The aim of the study is to explore the suitability and sustainability of a range of different rotation and cultivation systems pertinent to growers in East Anglia.

The experiment is a fully replicated factorial design with three replicates. Each plot is 36 m × 36 m to facilitate the use of farm scale equipment and techniques. Permanent grass pathways on the site allow each plot to be accessed independently. In each plot the outside area is treated as a 'headland' and all assessments and samples are taken from the central areas on the plots. Each treatment is managed in accordance with the specific requirements of that approach and all inputs are consistent with local best practice.

Rotation and cultivation systems

Four different methods of cultivation and four different types of rotation are used within the research project. This forms part of a fully factorial design delivering 16 treatments. All rotations grow wheat every second year, the year between is a break crop/fallow year. Winter cropping has a winter sown break crop, spring cropping a spring sown break crop, continuous wheat grows wheat every year and the alternate fallow grows wheat one year and is left fallow (with a mustard cover crop) the next. Cultivation approaches follow an annual plough approach, a shallow or deep non-inversion approach (typically using tine and disc based systems) or a managed system where cultivation techniques are decided on an annual basis. Further treatment description is given in Table 1.

Table 1. *An outline of rotation and cultivation treatments in the STAR project*

		Cropping and harvest year					
	Rotation	2006 (Year 1)	2007 (Year 2)	2008 (Year 3)	2009 (Year 4)	2010 (Year 5)	2011 (Year 6)
1	Winter cropping	Winter oilseed rape	Wheat	Winter beans	Wheat	Winter oilseed rape	Wheat
2	Spring cropping	Spring Beans	Wheat	Spring Oats	Wheat	Spring Beans	Wheat
3	Continuous wheat	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat
4	Alternate fallow	Fallow	Wheat	Fallow	Wheat	Fallow	Wheat

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

Results

Yield and margin data

Long term yield responses over project years 1–6 are presented in Table 2. Yields are presented as a percentage of the ploughed treatment within each rotational strategy and averaged across all seasons. Long term cumulative gross margin data (calculated as gross output minus input and machinery costs) over the same period are presented in Table 3. Cumulative gross margin trends over project years 1–6 for the rotation and cultivation systems are presented in Figs 1 and 2 respectively. Prices for key inputs and grain were based on 'spot prices' in the season of production.

Table 2. *Long term yield responses over project years 1–6 of the STAR project; presented as a percentage of the ploughed treatment within each rotational strategy and averaged across all seasons*

	Relative yield return (relative to ploughed approach)				
	Winter	Spring	Cont	Alt Fallow	Average
Plough	100	100	100	100	100
Managed	95	99	110	92	99
Shallow	93	91	103	96	96
Deep	98	97	98	98	98
Average	-	-	-	-	

Table 3. *Long term cumulative margin responses over project years 1–6 of the STAR project; calculated as gross output minus input and machinery costs based on spot prices in the year of production*

	Cumulative gross margin – machinery cost (£ ha^{-1})				
	Winter	Spring	Cont	Alt Fallow	Average
Plough	2989	1986	1280	1637	1973
Managed	2966	2046	1683	1410	2026
Shallow	2372	2017	1546	1635	1893
Deep	3158	2067	1236	1641	2026
Average	*2871*	*2029*	*1436*	*1581*	

With regard to cultivation, on average, ploughing resulted in the highest yields, with a drop of around 1% in yield to the 'managed programme', 2% to the 'deep tillage' systems and 4% to the 'shallow tillage' systems. Considering rotational approach, within the individual systems there is some variation in the ranking order, but in three out of the four systems the shallow tillage system has delivered the lowest yield return. Considering rotation alone the winter cropping rotation system has delivered the greatest returns followed by the spring cropping rotation, with the continuous wheat and alternate fallow systems resulting in lower returns.

Detailed yield and margin data for the 'cultivation × rotation' treatments for the last two cropping seasons, 2010 (season 5) and 2011 (season 6) harvest, are presented in Tables 4 and 5. While the dry spring of 2010 had some impact on yield (notably in the spring bean crop), the drought conditions in spring 2011 resulted in considerable yield loss in all rotations and systems. Ear numbers of in excess of 400 m^{-2} would be considered typical on this site to maximise yield. During 2011 ear numbers of 320–330 ears m^{-2} were recorded in all rotations in the STAR project except the continuous wheat, which had around 280 ears m^{-2}. Met Office data indicates that

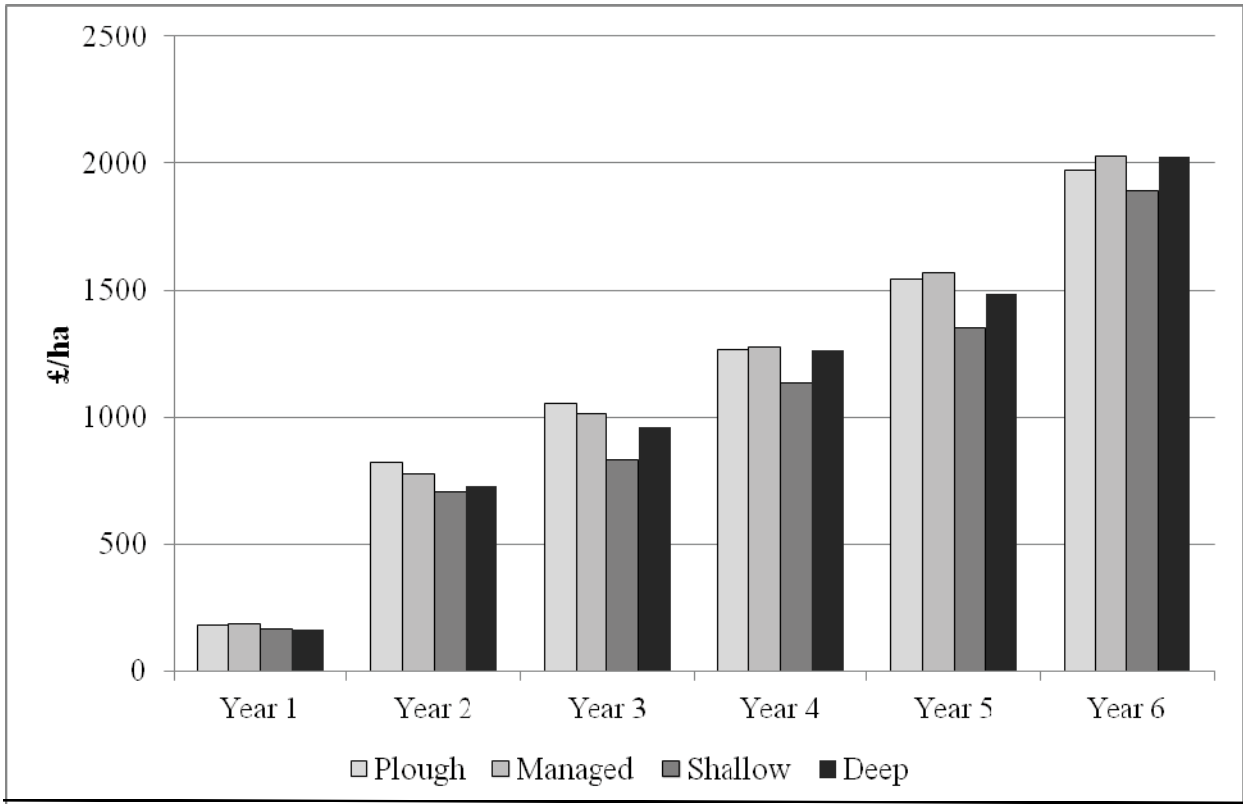

Fig. 1. Cumulative gross margin accumulation through the rotation with bars showing the different cultivation systems.

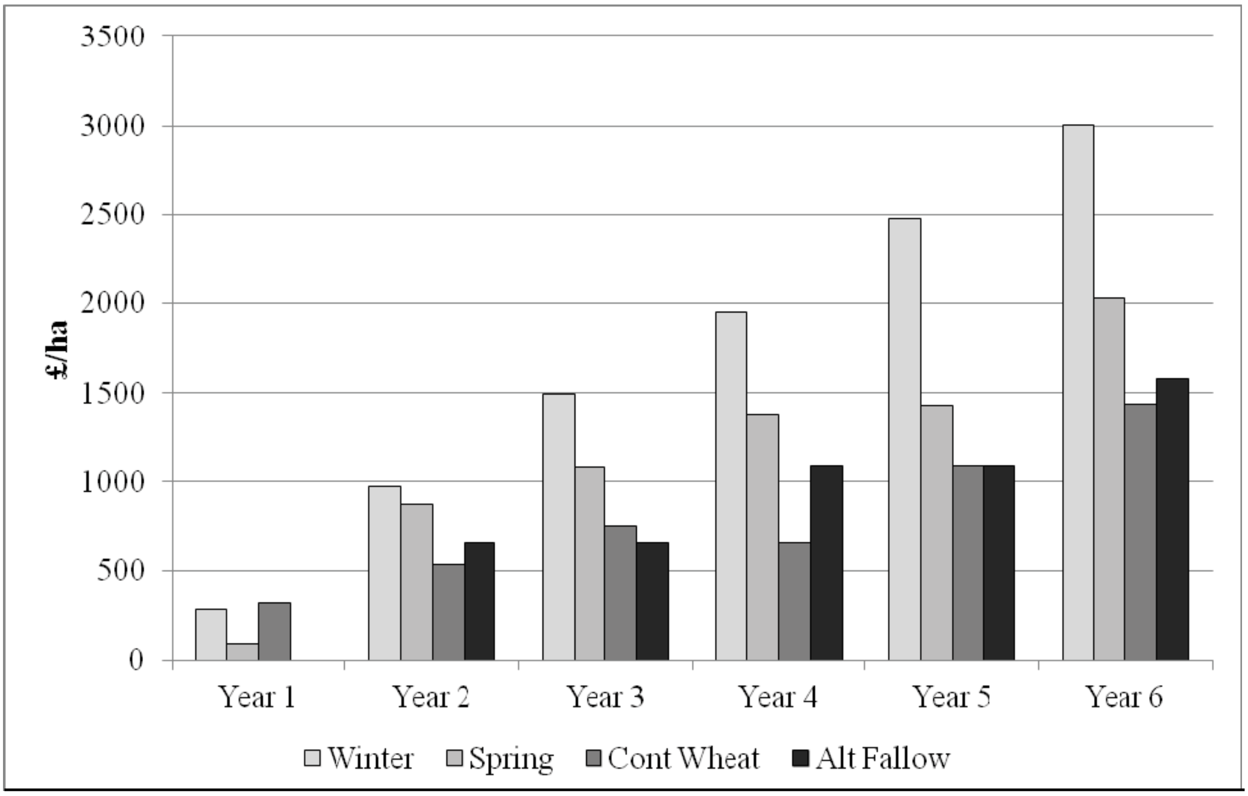

Fig. 2. Cumulative gross margin accumulation through the rotation with bars showing the different rotations.

Suffolk had a total of around 24 mm of rain over March, April and May 2011; with many areas only receiving 20–30% of their long term average rainfall.

Table 4. *The impact of rotation and cultivation system on yield (t ha^{-1}) and margin (£ ha^{-1}) in 2009/10*

	Yield (t ha^{-1})				Gross margin – machinery cost (£ ha^{-1})			
	Winter	Spring	Cont	Alt Fallow	Winter	Spring	Cont	Alt Fallow
Plough	3.47	2.70	8.21	-	486	77	524	-96
Managed	3.61	2.63	8.29	-	558	67	534	-96
Shallow	3.35	2.17	6.88	-	531	33	322	-96
Deep	3.55	2.13	6.96	-	542	16	322	-96
Average	*3.50*	*2.41*	*7.59*	-	*529*	*48*	*426*	*-96*
LSD t ha^{-1}	0.47	0.53	0.92	-				
CV %	6.8	11.0	6.1	-				

Plots in break crop / fallow;
Prices based on Wheat £130 t^{-1}; Beans £140 t^{-1}; OSR £280 t^{-1}; Diesel 50 ppl;
Nitrogen 66p kg^{-1} N (AN) or 56 p kg N^{-1} (Liquid).

Table 5. *The impact of rotation and cultivation system on yield (t ha^{-1}) and margin (£ ha^{-1}) in 2010/11*

	Yield (t ha^{-1})					Gross margin – machinery cost (£ ha^{-1})			
	Winter	Spring	Cont	Alt Fallow	Average	Winter	Spring	Cont	Alt Fallow
Plough	7.33	7.40	5.67	6.93	6.83	526	536	201	466
Managed	6.91	7.57	6.37	6.47	6.83	496	595	327	418
Shallow	6.85	7.83	7.44	7.15	7.32	487	634	500	532
Deep	7.65	7.95	6.63	7.35	7.40	595	640	366	550
Average	*7.19*	*7.69*	*6.53*	*6.98*		*526*	*601*	*349*	*492*
	LSD = 0.978		CV = 8.3						

All plots in winter wheat (cv. Oakley);
Prices based on Wheat £150 t^{-1}; Diesel 65 ppl;
Nitrogen 75p kg^{-1} N (AN); 70p kg^{-1} N (Liquid) or 65p kg^{-1} N (Urea).

Agronomy and soils

Data from the STAR project also demonstrates the impact of rotation and cultivation strategy on grass weeds. In the continuous wheat rotation substantial changes in grass weed burden have become apparent in relation to cultivation approach over the duration of the project. At the project outset there were no substantial grass weed issues in the field (although grass weeds were present). Despite targeted herbicide programmes, by 2008 (season 3) grass weed head numbers in non-inversion continuous wheat treatments were around 15 heads m^{-2}; mainly meadow brome (*Bromus commutatus*) with some other species including black-grass (*Alopecurus myosuroides*). By 2009 (season 4) non-inversion continuous wheat treatments were resulting in 22–45 grass weed heads per m^2 (mainly meadow brome). Following an intensive herbicide programme over the 2010 season (season 5), including a series of autumn residual herbicides and spring applied ALS material, the number of meadow brome heads in the non-inversion continuous wheat treatments were reduced to < 6 per m^2; with an associated herbicide cost in excess of £100 ha^{-1}. In addition to the data previously described in this paper detailed soil assessments, not included for brevity, have detected changes in soil penetration resistance, bulk density and water infiltration ostensibly with respect to cultivation practice. Soil penetration resistance data is suggesting the development of a pan in the ploughing approach and generally tighter soils in the sustained shallow tillage systems. Tighter soils have also been associated with reduced water infiltration.

Discussion

Considering long term responses to cultivation practice, the STAR project suggests higher yield returns from plough-based systems, in addition results suggest that the poorest performance is generally associated with the shallow non-inversion tillage approach. It has been speculated that the soils should adapt to the shallow non-inversion systems over time with associated yield recovery; this has not been apparent in the first 6 years of the STAR project.

However, yield only provides a broad measure of system performance and margin is the more pertinent parameter. With regard to gross margins it is perhaps surprising how close all of the cultivation systems are in terms of cumulative return. Over the first 6 years of the project there has been some movement in which system has delivered the highest return. Over harvest seasons 1–3 ploughing resulted in the highest return, while in seasons 4–6 the 'managed approach' surpassed the return delivered by the ploughed approach. In year 6 the cumulative return offered through the 'deep tillage' approach delivered on a par with the managed approach. It is perhaps quite comforting to many growers that the cultivation system giving the best performance on average is the 'managed approach'; that is selecting the approach on a seasonal basis to best suit the conditions and the crop. While the poor performance of the shallow non-inversion system and the strong performance plough-based approach are of interest, even this interpretation needs to be refined in terms of the overall farm system. For example, while ploughing may be delivering a relatively robust return on a per hectare basis this would not necessarily be reflected in speed of working, timeliness and land area covered. Similarly it could be argued overall mechanisation approaches in shallow tillage systems could present substantially different cost structures (e.g. smaller equipment with lower fuel costs).

With regard to rotational practice, it is apparent that the 'winter cropping' rotation is delivering the highest and most consistent cumulative gross margin and is some way ahead of the 'spring cropping' approach. The lowest cumulative returns have generally been associated with the continuous wheat and the alternate wheat fallow approaches. The 'continuous wheat' approach has delivered negative margins in some seasons and it should be noted that the cumulative margin data presented for the 'alternate fallow' systems does not include the cost of the cover crop. While this cost can vary substantially depending on the choice of cover crop and the management requirements, over the 2010 harvest season the mustard cover crop cost £95 ha^{-1}. Applied over the first 6 years of the STAR project this could further reduce the 'alternate fallow' margin by around £285.

Considering agronomic issues arising from the STAR project, the grass weed issues in the non inversion continuous wheat plots are worthy of note. This issue has developed since the initiation of the project and, as yet, there are no appreciable grass weed management issues in any of the other rotational approaches. The value of rotation and cultivation techniques (particularly the grass-weed control potential afforded through soil inversion) as weed managements tool are going to become increasingly important in light of developing resistance issues and loss of key active ingredients (Orson, 2011). Managing mixed grass weed populations, such as those present in the continuous wheat, presents a challenge to growers. The mix of meadow brome (known to emerge over a protracted period across the winter) and black-grass (emerging mainly in the autumn) (HGCA, 2009) gives rise to timing issues (particularly for ALS herbicides) to maximise control and minimise crop competition. In addition these strategies can also substantially increase herbicide costs. To this end while spring cropping and potentially fallow approaches may well have a role to play (Moss *et al*., 2011), the higher margins offered by winter cropping approaches will remain attractive to growers.

Conclusions

Farming systems studies, such as the STAR project, provide increasingly powerful interpretation of long term trends in rotational performance. The farm rotation typically employs a range of crops and cultivation techniques and it is important therefore that research programmes continue to consider the rotation as a whole and the sustainability and interactions of the individual elements involved. Going forward it is essential that long term systems studies, like the STAR project, are maintained, to provide demonstration hubs for best practice, test beds to evaluate new systems and importantly to continue to provide impartial information to allow growers to make informed decisions.

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References

HGCA. 2009. *The Encyclopaedia of Arable Weeds*, publication G47.

Orson J. 2011. Strategies for sustainable *Alopecurus myosuroides* (black-grass) control in winter wheat. *Aspects of Applied Biology* **106**, *Crop Protection in Southern Britain*, pp. 11–16.

Moss S R, Orson J, Froud-Williams R J. 2011. Fallowing for the control of annual grass weeds: what are the issues? *Aspects of Applied Biology* **106**, *Crop Protection in Southern Britain*, pp. 17–22.