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CROP SPECIFIC IMPLICATIONS OF YIELD AND ENERGY USE EFFICIENCY IN NON-INVERSION TILLAGE SYSTEMS

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Summary: This paper reports how non-inversion (reduced) tillage impacts energy consumption and crop yield, utilising 8 years of replicated field trials undertaken by The New Farming Systems study in the East of England. Tillage regimes include: (1) plough, (2) shallow non-inversion (typically 10 cm), and (3) deep non-inversion (20-25 cm) within two rotations of either (1) winter sown / spring sown crops or (2) winter sown / spring sown + autumn cover crop.

Energy use per ha (highest to lowest) was: plough > deep non-inversion > shallow non-inversion. Crop specific and temporal yield responses were observed. Winter sown crops responded favourably to deep non-inversion tillage, and yields improved as the trial progressed. When considered in combination with lower energy input per hectare, energy efficiency increased relative to the plough-only control. Yield response to shallow non-inversion tillage was variable. Spring sown crops declined in yield and therefore overall energy efficiency.

INTRODUCTION

Reduced or non-inversion tillage has been cited by a number of authors as a potential means to improve the efficiency and resilience of arable cropping (for example Lal *et al*., 2007). Arable cropping has traditionally used plough-based systems that invert the soil with a mouldboard plough, followed by a secondary cultivation prior to drilling (Bell, 1996; Gajri *et al*., 2002). The potential degradation associated with sustained ploughing, for example, soil erosion and a decline in biological activity, have been cited as contributors to reduced crop productivity and a decrease in the resilience of the system (Lal *et al*., 2007; Morris *et al*., 2010; Natural England, 2012).

Alternatives to ploughing include non-inversion tillage. Carter *et al*. (2003) describe this as being either shallow (5-10 cm) with crop residues remaining mostly on the soil surface, or deep (15-20 cm) where a proportion of residues are incorporated into the topsoil. Soil compaction, a potential risk associated with reduced cultivations, may be removed by deep non-inversion tillage using a subsoiler (Batey, 2009). Non-inversion tillage is reported to be advantageous due to decreased operational time and decreased energy input per ha (Cannell, 1985). A failure to take account of potential reductions in crop yield, however, risks endorsing a strategy that increases energy consumption per t of crop output. Knight *et al*. (2012) report an initial decrease in crop yield immediately after conversion to a non-inversion tillage system, that then increases and stabilises over time. A key question to address is whether this yield reduction reduces energy efficiency, and if so, in which crops and for how long.

The New Farming Systems (NFS) research programme is comprised of several long-term field trials that aim 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 started in 2007 and is currently in year 8 of what will be a minimum 10 year trial. This paper reports on the impact of non-inversion tillage on energy consumption per unit of crop yield accounting for crop type, and temporal variability in crop yield, relative to time after implementation. The importance of long-term field trial research is highlighted.

MATERIALS AND METHODS

Tillage treatments

The NFS trials are a complete or incomplete factorial design of four replicates 12 m × 36 m in size (Stobart and Morris, 2011). Samples were taken in central plot areas. The specific tillage depth and secondary cultivation(s) varied according to crop and season (Table 1). The shallow non-inversion trial was typically 10 cm in depth using a tine and disc based approach. All crop trials followed local best agronomic practice. Where a cover crop is present, fodder radish (*Raphinus sativus*) was sown at 10 kg ha^{-1} either in late August or early September, then destroyed and incorporated before drilling the spring sown crop.

Energy consumption

A Life-Cycle Assessment (LCA) approach has been followed drawing on previous assessments of energy consumption for agricultural commodities (Hülsbergen and Kalk, 2001; Tzilivakis *et al*., 2005; Williams *et al*., 2009). The system boundary extends to pre-harvest. Operations associated with the tillage trials include indirect emissions from agro-chemical manufacture (Audsley *et al*., 2009; Williams *et al*., 2009), especially inorganic nitrogen (N) fertiliser manufacture (Brentrup and Pallière, 2008), and from farm machinery (Hülsbergen and Kalk, 2001; Williams *et al*., 2009). Energy consumption attributed to each scenario (Table 1) has been derived for:

1. Direct (on-farm) from machinery operation (Scope 1): pesticide spraying, fertiliser spreading, tillage depending on soil type, and depth and the type of crop sown (Table 1).
2. Indirect from product manufacture (Scope 3): pesticides and fertilisers, their packaging, storage and transport (to farm).
3. Indirect from machinery manufacture (Scope 3): estimation of depreciation per operation or hours of use (Table 1).

Table 1. Energy consumption (MJ) attributed to direct (*D*) and indirect depreciation (I_d) components of field operations. D_{min} and D_{max} refer to the minimum and maximum values within the range.

Operation	D_{min}	D_{max}	I_d	Treatment (primary)	Treatment (secondary)
chain harrow	233	-	143	-	[a]CC
cultivator drill	914	-	227	all	-
Einbok rake	182	185	152	-	[b]CC
plough (20 cm)	717	1026	143	Pl	-
plough (25 cm)	998	-	143	Pl	-
roll	87	197	28	-	[c]CC
shallow disc cultivation	277	387	28	-	all[d,e]
subsoil (35 cm)	828	1612	143	D-NI[f]	-
non-inversion deep (20 cm)	253	513	152	D-NI	-
non-inversion shallow (10 cm)	164	-	76	S-NI	D-NI[f]

[a]with cover crop 2011; [b]with cover crop 2009; [c]with cover crop 2009 & 2011; [d]all treatments in 2012, 2013, 2015; [e]*2 in plough *1 D-NI and S-NI in 2012; [f]spring oilseed rape only. Pl (plough); S-NI (shallow non-inversion); D-NI (deep non-inversion).

RESULTS

Tillage treatments

Energy consumption was equal for pesticides and fertiliser in all treatments. Variables correspond to differences in tillage and the presence or absence of a cover crop. The energy input ratio given in Table 2 is calculated as:

$$\text{Energy input ratio} = \frac{\text{energy per unit of yield (GJ t}^{-1}\text{) for treatment x in year n}}{\text{energy per unit of yield (GJ t}^{-1}\text{) for plough-only (control) in year n}}$$

A ratio greater than or equal to one (normal text) indicates either no change or a decrease in energy efficiency (greater energy consumption per unit of yield). A ratio of below one (bold text) represents energy consumption less than the plough-only control.

The plough-only control treatment had the highest yields during the early phase of the field trials, especially in the spring sown crops (spring beans and spring oilseed rape), coupled with the lowest energy input per t of yield. Yield improvements and an increase in energy as indicated by a ratio of below one (Table 2), were evident later in the non-inversion treatments post 2011 onwards, especially the deep non-inversion in winter wheat. The energy input associated with cultivations is summarised in Figure 1. The greater input to the plough treatments in 2012 reflects the two shallow disc cultivations in addition to the primary tillage operation.

Table 2. Energy input ratio (GJ t^{-1}) for each treatment relative to the conventional plough (control) treatment (bold text denotes reduced compared to control).

Operation	SOSR 2009	WW 2010	SBN 2011	WW 2012	SBRLY 2013	WOSR 2014	WW 2015	WW mean
Plough	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Deep NI	1.28	1.00	1.40	**0.93**	**0.97**	**0.89**	**0.91**	**0.95**
Shallow NI	1.17	1.06	1.72	**0.93**	1.04	**0.82**	**0.98**	1.00
Plough + CC	1.31	1.02	1.77	1.01	1.10	1.14	1.01	1.01
Deep NI + CC	1.49	**0.98**	1.65	**0.93**	1.08	**0.98**	**0.95**	**0.95**
Shallow NI + CC	1.23	1.07	2.30	**0.90**	1.04	**0.89**	**0.97**	**0.99**

SOSR (spring oilseed rape); WW (winter wheat); SBN (spring beans); SBRLY (spring barley); WOSR (winter oilseed rape); S-NI / D-NI (shallow / deep non-inversion); CC (cover crop).

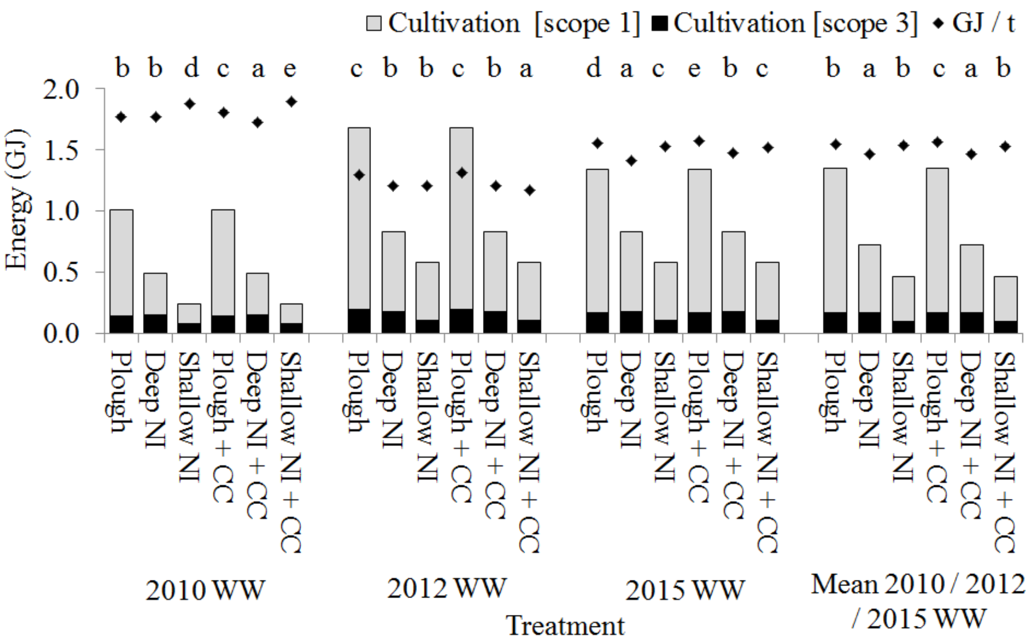

Figure 1. Energy input (GJ ha^{-1}) from cultivations and mean energy input per unit of yield (GJ t^{-1}) ± 1 SE (standard error) of the mean. Different letters denote >1 SE (to 2 decimal places) of the mean GJ t^{-1}.

This improvement is evident for the three years of winter wheat overall. The shallow non-inversion tillage has an equal input per tonne compared to ploughing, although this is partially skewed by the higher value during 2010, early in the trials. Yields in the shallow non-inversion tillage treatments were more variable, although the addition of a cover crop appeared to be beneficial in 2012 and 2015.

DISCUSSION

Energy inputs to the non-inversion tillage treatments, with the exception of deep non-inversion spring oilseed rape when a sub-soiler was used to break up a pan identified by a penetrometer, were lower per ha compared to conventional ploughing, supporting the conclusions drawn by Cannell (1985). Energy input was lower due to a shallower cultivation depth (typically 20 cm or less as opposed to 23cm) and not inverting the soil. An interesting output was the apparent crop specific response to reduced tillage, with greater benefit realised by the winter sown crops. Secondly, the deeper non-inversion tillage appeared to be a more effective approach than shallow non-inversion tillage. The deep non-inversion treatment in the winter sown crops produced consistently higher yields compared to the conventional plough treatment post 2011 onwards (0.8 to 9.1%) and relative to the shallow non-inversion treatment (2.0 to 30.3%) with the exception of winter oilseed rape (-5.5%). It concurs to a degree with Knight *et al*. (2012) who report that yields tend to improve and stabilise after an initial decline. Energy efficiency also improved per tonne of yield relative to the plough-only control, as the trial progressed.

Of the crops considered, spring beans had the least positive response to non-inversion tillage, with the largest yield reduction relative to ploughing (-51.1 to -52.5%), combined with the energy associated with a cover crop where applicable. Morris *et al*. (2014) also observed that yield loss in non-inversion tillage systems appeared to manifest itself mainly in the spring break crops. Yields might, according to Knight *et al*. (2012), be expected to improve with time, as illustrated by winter wheat in this study. Indeed, Godwin (2014) report that non-inversion tillage has a negligible impact on spring bean yield, therefore, a further assessment of spring beans grown at a later stage in the trial would be beneficial. The yield improvements recorded in winter wheat and the potential crop specific impact of non-inversion tillage emphasise the importance of long-term field trials, which may have been otherwise overlooked if considered over a shorter timescale. The deep non-inversion tillage approach appears to offer benefits both in terms of reduced energy consumption and improvements in yield for winter sown crops.

A review of the literature by Morris *et al*. (2010) concludes that non-inversion tillage is generally more suitable for self-structuring clay soils, where the risk of excessive clod formation post-cultivation of wet soils is decreased. In terms of energy consumption, the decrease in fuel noted on the sandy clay loam soil in these trials might be decreased further if implemented on heavier clay soils (Hulsbergen and Kalk, 2001; Williams *et al*., 2009). This would also be more applicable to the winter sown crops in which yield improvements were typically observed. Winter crops tend to dominate areas where heavier soils are present, due to the limited potential for machinery to gain access to the field during the spring if wet.

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