USING REDUCED TILLAGE TO IMPROVE THE EFFICIENCY OF ECOSYSTEM SERVICE DELIVERY ON ORGANIC FARMS

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SUMMARY

Organic farming practices aim to maximise the delivery of ecosystem services in the agricultural landscape. However, in order to maintain optimal crop productivity the mouldboard plough is often used to control weeds and this can have negative effects on a range of soil parameters, thereby jeopardizing delivery of these services. Reduced tillage (RT) can be beneficial to soils and could improve both the efficiency of production and the delivery of ecosystem services on organic farms. However, abandoning the plough on organic farms is challenging due to impaired weed control. Here we report on a two year trial where an RT system with the Ecodyn, with duck feet shares operating at a depth of 7.6 cm in combination with seed drilling, was compared with mouldboard ploughing. Spring oat and spring barley establishment was improved under RT. Weed cover and biomass was greater under RT, but there was no difference in cereal grain yields in either year. The RT system used 71% less fuel and tillage operations took 72% less time that the plough system.

INTRODUCTION

The delivery of multiple ecosystem services is a core principle of organic farming. In pursuit of this goal, organic farming systems incorporate into the landscape functional diversity (at the crop, variety and genetic level) in both space and time. By diversifying crop rotations and avoiding agrochemicals, levels of soil organic matter are often greater, biodiversity is often increased (Mäder *et al.*, 2002) and the energy efficiency of the production system can be greater on organic farms when compared to conventional farming systems (Chappell and LaValle, 2011). However, there are costs associated with the delivery of ecosystem services associated with organic farming practices – in particular those associated with the use of soil tillage.

Soil inversion using a mouldboard plough is an effective means of controlling weeds without the need for herbicides, but it can also be associated with negative effects on a number of soil parameters including habitat disturbance of soil organisms, increased losses of soil organic matter and emissions of greenhouse gases (Holland, 2004). On the other hand, negative effects associated with mouldboard ploughing can be compensated for with the use of organic manures and cover crops in organic rotations (Teasdale *et al.*, 2007). Additionally, periods of grass-clover ley that leave the soil undisturbed for up to 4 years of the rotation can increase the density and biomass of soil organisms (Lampkin, 1990; Mäder *et al.*, 2002; Riley *et al.*, 2008).

Nevertheless, there is evidence that reducing the intensity of soil tillage can provide benefits to soil health and could further improve the efficiency of ecosystem service delivery and food production on organic farms (Holland, 2004; Peigné *et al.*, 2007).

Currently, 44% of conventionally farmed arable land in England is cultivated with reduced or zero tillage (National Statistics, 2010). However, this figure is likely to be much lower for organic farms where the adoption of RT presents more of a challenge as numbers of weeds, particularly perennial species, often increase and persist in subsequent cash crops and can reduce grain yields (Peigné *et al.,* 2009). While herbicidal applications allow conventional farmers to control weeds after RT, on organic farms the development of innovative cultural and mechanical approaches to weed control is required to make RT viable.

Here we report results from a two-year study conducted on an organic farm in which mouldboard ploughing was compared with the use of a reduced tillage machine. The trial is part of a collaborative EU project (TILMAN-ORG www.tilman-org.net) which brings together results from 27 trials comparing reduced tillage with mouldboard ploughing across 10 European countries.

MATERIALS AND METHODS

A randomized complete block trial with three replicates was conducted over two spring growing seasons (2010 and 2011) on an organic farm in Gloucestershire, England (51°39'N, 2°09'W, 142 m). Three fields (average 5.2 ha) on a clay/clay-loam soil were split into two tillage treatments: conventional mouldboard ploughing and reduced tillage. The conventional mouldboard ploughing treatment (hereon "Plough") comprised of a powerharrow and mouldboard plough at 15 cm soil depth. In the reduced tillage treatment (hereon "RT") an innovative machine, the Ecodyn cultivator (www.eco-dyn.com), was used to loosen the soil with duck feet shares at a depth of 7.6 cm in combination with seed drilling.

On 14 April 2010 both tillage treatments were drilled with the Spring Oat cultivar Husky at 190 kg/ha. After harvest both treatments were sown with a green manure cover crop mixture of stubble turnips, forage rape and mustard. In 2011 both treatments were drilled with the Spring Barley (cultivar Westminster). Average rainfall during the 2010 growing season was 55.6 mm, and during the 2011 growing season was 45.5 mm. Average air temperature was 12.2°C in 2010 and 11.9°C in 2011.

In 2010 soil cores were taken from six locations across each plot on two occasions. On the second occasion samples were taken from three soil depths: 0-15 cm, 15-30 cm and 30-60 cm. Samples were bulked and air dried before two subsamples were analysed per plot. Organic carbon was determined using the wet oxidation method. Organic nitrogen was assessed using the Kjeldahl method. Phosphorus mg/l was determined according to the Olsen P method and Potassium was determined using flame photometry. Soil data for 2011 are not available.

Percentage crop cover, crop plant density and ear density were assessed in four 0.25 m^2 sectioned quadrats in each plot in both years. Weed infestation was measured using the same method of percentage cover and in 2010 dry matter biomass from four 0.25 m^2 subplots in each plot was measured. Grain yield was determined by cutting the crop at ground level in four 1 m^2 quadrats in each plot, and fuel costs and time to carry out cultivation and seed drilling were calculated on each operation. All data were analysed using one-way ANOVA with the statistical software R, version 2.13.1 (Crawley, 2007).

RESULTS

Crops

In both growing years crop cover after establishment was significantly greater in RT plots ($p<0.01$ and $p<0.05$ in 2010 and 2011, respectively, Table 1). Plant density was also higher in RT plots although the difference was not significant ($p>0.05$). Ear density in RT was higher by 104 plants/m^2 in 2010 (p<0.0001) but similar to plough in 2011. In 2010 oat straw length was on average 10 cm longer in RT plots (p<0.05) whereas both the straw length and ear length of barley in 2011 were longer in Plough plots (8.5 cm and 2.3 cm respectively; $p<0.01$ and $p<0.001$).

In both years, the average yield on RT plots was 0.1t/ha higher on RT plots but this difference was not significant in 2010 or 2011 ($p>0.05$, Table 1).

Weeds

In 2010 weed cover and biomass were greater in RT plots ($p<0.001$; $p<0.05$) in the early season (May) but there was no difference later in the growing season (June) ($p>0.05$). In 2011 average weed cover tended to be higher in RT plots in both the early (May) and late (August) season, although neither difference was significant ($p>0.05$).

Fuel Costs and Man Hours

In 2010 the RT system used 14.02 litres of fuel/ha and took 30 minutes/ha to carry out all operations including seed drilling. The Plough system used 48.18 litres/ha and 108 minutes/ha in man hours. Thus, RT used 71% less fuel and 72% less time than the Plough system.

Soil

In 2010 there was no significant difference between tillage treatments for any of the soil parameters investigated ($p>0.05$).

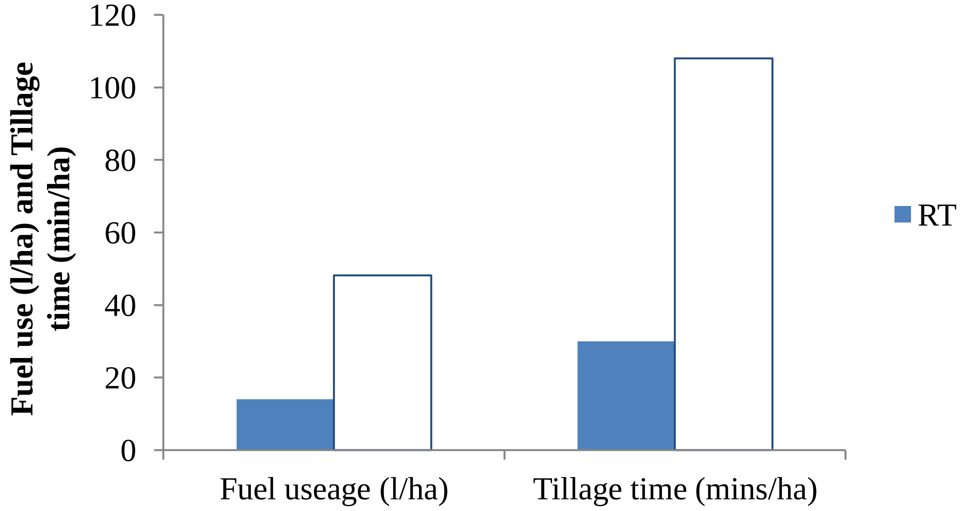

Figure 1: Fuel use and tillage time associated with RT and Plough systems in 2010

Table 1: Mean crop cover, weed cover (May) and grain yield in 2010 and 2011

	Crop cover (%)	Weed cover (%)	Grain yield (t/ha)
2010			
Reduced tillage	29	11	4.3
Plough	6	0	4.2
	**	***	Ns
2011			
Reduced tillage	74	7	4.8
Plough	50	0	4.7
	*	Ns	Ns

ANOVA: ns, not significant, ***P<0.001, **P<0.01, *P<0.05.

DISCUSSION

Dry sowing conditions in both 2010 and 2011 meant crop cover and plant density of spring oat and spring barley was greater in plots treated with RT when compared to those treated with the Plough. RT can improve the establishment of cereal seed as lower soil aeration promotes moisture conservation and increases in soil organic matter associated with RT can produce soil structural conditions conducive to improved infiltration rates and greater water holding capacity (Vakali *et al.*, 2002; Krauss *et al.*, 2010). However, when soil moisture is not a limiting factor, weed control may become more important in determining crop performance (Vakali *et al.*, 2002; Peigné *et al.*, 2009). In the present study, dry sowing conditions meant seed sown under the RT system gained an early advantage that outweighed or offset the greater weed pressure found on RT plots later in the season. Longer term trials examining the effects of RT on organic rotations have reported increases in the abundance of weeds along with a change in the community composition to perennial species including competitive grass weeds (Peigné *et al.*, 2007). In the present trial, total weed cover was low in both years and in both treatments (11% and 6% in RT plots and 0% and 1% in Plough plots in 2010 and 2011, respectively) suggesting the RT machine used in the trial was able to constrain the weed population below an economically significant threshold, but the composition of the weed community may change over time. It is planned to continue the experiment for at least 2 more years in order to monitor the weed community.

During the first year of conversion to RT there was no difference in the soil nutrient profiles between tillage systems. Weed infestation and soil moisture were the key factors determining crop performance. However, RT can result in slower soil warming in spring and delayed mineralisation and supply of nitrogen to crops (Berner *et al.*, 2008). In 2010 straw length was longer and head density was higher in RT plots as a result of improved crop development resulting from greater soil moisture availability during dry growing conditions. In 2011 straw and ear length of barley plants were significantly shorter in RT plots. Although soil nutrient data are not available for 2011 it is likely that the inhibited development of barley grown under RT is related to a lack of synchronicity between supply and demand of soil nutrients. Interactions between crop performance and crop type under RT systems have been reported previously (Berner *et al.*, 2008; Vakali *et al.*, 2011). Berner *et al.* (2008) observed reduced yield of winter wheat under RT but an oat-intercrop was unaffected by tillage treatment. Winter wheat has a high nitrogen demand early in the growing season and as a result delayed mineralisation after RT can inhibit plant development, whereas nitrogen demand in oats is lower and later in the season so plants are less affected by delayed mineralisation associated with RT. In the present trial neither oat nor barley yield was affected by tillage type; however the shorter straw and ear length observed in the barley crop suggests the plants suffered from delayed mineralisation. Higher ear density in RT plots counterbalanced shorter ear lengths and as a result there was no difference in grain yield between tillage treatments.

Reducing the intensity of soil tillage typically involves a shallower working depth that requires reduced power input and allows higher forward speeds that can increase the work rate in comparison to ploughing. The reduced tillage machine trialled in this study lowered fuel consumption by 34 litres of diesel per hectare and decreased by 78 minutes per ha the time to carry out tillage operations while attaining a grain yield comparable to plots treated with the Plough. As a result production efficiency in terms of the ratio of energy in to energy out was improved in RT plots.

Agriculture directly contributes 10-12% of greenhouse gas emission globally; and this figure rises to 30% or more when land conversion and costs beyond the farm gate are added (Smith *et al.*, 2007). Diminishing oil resources and international agreements to reduce emissions of CO_2 require innovation in new sustainable technology. RT has become a viable soil management practice for conventional arable production and can be beneficial to soil structural properties and can reduce fuel consumption (Krauss *et al.*, 2010). In the current trial the integration of RT into an organic rotation improved the efficiency of production by reducing the fuel and time to establish a crop while maintaining cereal grain yields and the ecosystem services associated with organic farming.

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REFERENCES

Berner A, Hildermann I, Fliessbach DA, Pfiffner DL, Niggli DU and Mäder DP (2008). Crop yield and soil fertility response to reduced tillage under organic management. Soil and Tillage Research 101, 89-96.

Chappell MJ and LaValle LA (2011). Food security and biodiversity: Can we have both? An agroecological analysis. Agriculture Human Values 28, 3-26.

Crawley M (2007). The R Book. John Wiley and Sons Ltd, Chichester.

Holland JM (2004). The environmental consequences of adopting conservation tillage in Europe: Reviewing the evidence. Agriculture, Ecosystems and Environment 103, 1–25.

Krauss M, Berner A, Burger D, Wiemken A, Niggli U and Mäder P (2010). Reduced tillage in temperate organic farming: Implications for crop management and forage production. Soil Use and Management 10, 12-20.

Lampkin N (1990). Organic farming. Farming Press Books, Ipswich.

Mäder P, Fliessbach A, Dubois D, Gunst L, Fried P and Niggli U (2002). Soil fertility and biodiversity in organic farming. Science 296, 1694-1697.

National Statistics (2010). Farm practices survey. The Department for Environment, Food and Rural Affairs, National Statistics.

Peigné J, Cannavaciuolo M, Gautronneau Y, Aveline A, Giteau JL and Cluzeau D (2009). Earthworm populations under different tillage systems in organic farming. Soil and Tillage Research 109, 207-214.

Peigné J, Ball BC, Roger-Estrade J and David C (2007). Is conservation tillage suitable for organic farming? A review. Soil Use and Management 23, 129–144.

Riley H, Pommeresche R, Eltun R, Hansen S and Korsaeth A (2008). Soil structure, organic matter and earthworm activity in a comparison of cropping systems with contrasting tillage, rotations, fertilizer levels and manure use. Agriculture, Ecosystems and Environment 124, 275-284.

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B and Sirotenko O (2007). Agriculture climate change mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

Teasdale JR, Coffman CB and Mangum RW (2007). Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement. Agronomy Journal 99, 1297-1305.

Vakali C, Zaller JG and Koepke U (2011). Reduced tillage effects on soil properties and growth of cereals and associated weeds under organic farming. Soil and Tillage Research 111, 133-141.

Vakali C, Sidiras N, Bilalis D and Koepke U (2002). Possibilities and limits of reduced primary tillage in organic farming. In: ldi TA, Lockeretz W and Niggli U (Eds.), 14th IFOAM Organic World Congress, Vdf, Zurich, Victoria, Canada, 27 pp.