The effect of traffic and tillage on crop growth and yield in a sandy loam soil

Smith, E.K., Misiewicz, P.A., Chaney, K., White, D.R., Godwin, R.J.
Harper Adams University, Newport, Shropshire, TF10 8NB, United Kingdom

ABSTRACT

This paper aims to provide an introduction to a long-term trial which has been established to investigate the interaction of 3 traffic systems (Random Traffic Farming, Low Ground Pressure, Controlled Traffic Farming) and 3 tillage systems (Deep Tillage to a depth of 250 mm, Shallow Tillage to a depth of 100 mm and Direct Drilling). It is widely accepted that traffic and tillage, because of agricultural production systems, influence soil quality, crop production and ultimately affect overall profitability. A 3x3 factorial experiment has been established in the United Kingdom to provide, for the first time, a single-site trial to determine the effects of the interaction of traffic and tillage on soil, crop and energy parameters. Results from the first experimental year show that the use of Controlled Traffic Farming with reduced tillage (Shallow Tillage) can increase harvestable wheat (*Triticum aestivum* var. *Duxford*) grain yield by as much as 9%. Direct Drilled plots led to reduced yields.

1. Introduction

Soil is the product of a complex set of interacting processes and cycles (Fitzpatrick, 1991) that act upon and within the soil (Gerrard, 2000) over time to create, if unobstructed, appropriate physical and chemical conditions to support crop growth (Forth, 1978). Plants require a network of pore spaces to support gas exchange (oxygen and carbon dioxide), water movement and nutrient uptake (Forth, 1978). If the soil environment is misused, as has happened continuously over time under intensive agricultural production, the ability of the soil to maintain these ideal conditions is compromised (Gerrard, 2000). The intensive cultivation of crops, using deep tillage or ploughing for example, has led to critical and costly levels of global soil degradation. The greatest contributor to global soil degradation is compaction (Hamza et al., 2005). Compaction leads to poor structure, low Soil Organic Matter (SOM) and soil fertility (Rowell, 1994), reduced water drainage (Forth, 1978) and an increased risk of erosion. All of these factors reduce the productivity of our soils and at a time when the pressures of a growing global population are ever increasing steps need to be taken to ensure the future of a sustainable agricultural production system.

Traffic and tillage management techniques, e.g. Low Ground Pressure Farming (LGP) or Controlled Traffic Farming (CTF) and conservation tillage (Shallow Tillage or Direct Drill), seek to reduce soil degradation and achieve a sustainable balance between production, protecting the environment and increasing profitably by minimising extensive soil compaction thus improving soil structure and soil organic matter. The intensity of traffic is fundamental to the extent and level of soil compaction (Hamza and Anderson, 2005). Random Traffic Farming (RTF) exposes as much as 86% of a field to soil deformation by compaction (Kroulik, 2011) and as machinery is becoming heavier the applied stresses effect both the surface and subsurface soils (Lamande and Schjonning, 2011) resulting in compaction that is more difficult to remove (Spoor et al., 2003). The first pass of a vehicle causes the greatest damage with just one pass negatively affecting all soil characteristics and responses (Hamza and Anderson, 2005). Water infiltration rate is greater in un-trafficked soils (Chyba, 2012) by as much as 400% (Chamen, 2011). Trafficking ultimately results in yield losses (Hamza and Anderson, 2005) in the region of a 20-80% (Chamen, 2011).

To minimise soil degradation it is essential that careful consideration be given to the timing and selection of running gear (i.e. tracks/ tyres) for the prevailing soil and climatic conditions to avoid soil degradation. One method of overcoming traffic-induced compaction is to reduce ground contact pressure and improve the uniformity of pressure distribution (Alakukku et al., 2003) by decreasing tyre inflation pressures or using specific LGP running gear (e.g. Michelin Axiobib tyres or rubber tracks). These technologies can minimise the pressures that penetrate into the soil profile from surface applied loads (Smith et al., 2013), provide improved tractive efficiency (Alakukku et al., 2003) and improve timeliness of field operations. RTF and LGP systems still permit the widespread trafficking of fields. In comparison, a traffic management system known as Controlled Traffic Farming restricts all field traffic to wheelways. Still in its infancy of adoption, CTF systems have already been found to minimise soil degradation (Tullberg et al., 2007), improve soil structure, water infiltration (Kingwell and Fuchsbichler, 2011; Voorhees and Lindstrom, 1984; Silburn and Glanville, 2002), improve crop productivity and yields and economic benefits (Tullberg et al., 2007). The on-farm benefits are already being seen across Australia and progressively so in the UK as uptake increases (Tullberg et al., 2007) and farmers develop solutions to overcome current restrictions associated with machinery working width compatibility (Tullberg, 2010). The future of sustainable agricultural production systems will have to balance soil protection, productivity and mechanization.

The level, and timing, of tillage plays an important role in determining the intensity of trafficking and the risk of compaction. Tillage is the most fuel intensive operation in crop production (Koga et al., 2003). Traditional use of intensive cultivations, i.e. ploughing or deep tillage, necessitates the increased use of large and heavy machinery which increases the vulnerability of the soil to compaction and degradation (Chamen et al., 2003). Previous research has found that soil pore systems are improved and support greater infiltration under conventional tillage compared to no tillage systems, but only in the absence of trafficking (Lipiec et al., 2006). Intensive cultivations are linked to increased machinery maintenance costs (Hamza et al., 2005), reduced structural stability and a greater risk of soil erosion (Rowell, 1995). A reduction in tillage, where soil disturbance is kept to a minimum (stubble breaking, dessication, shallow tillage, seeding, applications, harvest), can reduce the area exposed to trafficking to 64% (Kroulik, 2009). Conservation tillage alone is associated with increases in SOM (Fitzpatrick, 1991) and, coupled with reduced trafficking, has been shown to reduce soil bulk density, improve water infiltration (Chen and Yang, 2013), moisture content and water quality, reduce loss of SOM and the risk of soil erosion and improve crop productivity (Holland, 2002; Sip et al., 2013). Conservation tillage is most extensively used in South America (45 million hectares) but uptake in Europe is markedly lower (1.3 million hectares (Trethowan et al., 2012)). Direct Drilling reduces the area trafficked even further to 42% (dessication, seeding, applications, harvest) (Kroulik et al., 2009). Minimum trafficking is essential in Direct Drilling systems as there is a greater risk of topsoil compaction in these systems (Munkholm et al., 2003) if extensive trafficking continues. Further complications can arise relating to timeliness of field operations particularly when planting and spraying (Tullberg et al., 2007).

The present study investigates the interactions of field traffic and soil tillage on the physical changes in soil structure, crop establishment and growth and system energy requirements. This paper presents results on the effect of traffic and tillage on harvestable yield for the first experimental year.

2. Material and methods

2.1 Field trial site

This study was conducted on a single field site covering 4 ha established in October 2011 at Harper Adams University, Shropshire in the United Kingdom. The site lies at 63 m above sea level with a mean annual rainfall of 712 mm and a mean annual air temperature ranging between 14.3 °C (maximum) and 6.1 °C (minimum) (2000-2010 average). Data on monthly rainfall and temperatures taken from the on-site weather station during the first two years of the trial (2011-2013) are given in Table 1. The 2012 spring, summer and early autumn season preceding the establishment of the experiment experienced notably higher than average rainfall. The preceding crop in 2011 was winter wheat, grassland in 2010 and barley in 2009 and 2008. The site is predominantly sandy loam with Ollerton (Ol) overlying Salwick (So) and locally prevailing wet subsoil for short periods throughout the year.

2.1. Site normalisation

In September 2011, prior to the establishment of the experimental field trial, a sub-surface gravel back-fill land drainage system with drains spaced at 13 m intervals was installed across the entire site. At the start of the project, the site underwent a process of normalisation: following 2 passes of a subsoiler to a depth 600 mm, and then ploughing, the site was established in a 4 m CTF system using a power harrow drill combination drilling winter wheat (*Triticum aestivum* var. *Duxford*). The 4 m wide passes that were created in October 2011 were the foundations of the plots to be used in subsequent years, and the wheelways trafficked in every plot for drilling have been defined in the experiment as the primary wheelways and will remain the drilling wheelways for the duration of the project. During the period October 2011 to September 2012 soil and crop properties were investigated using in-field and remote sensing techniques to characterise spatial variation and determine the most homogenous, and therefore most suitable, location of the subsequent plot trials (Kristof et al., 2012). Individual yields for each 4 m plot, harvested in September 2012, were calculated by grain weight removed and showed that the proposed trial site uniformly yielded 4.2 ±0.2 t/ha.

Table 1
Total monthly rainfall and average maximum and minimum air temperatures (T (°C)) over the normalisation year and the first experimental growing season (2012-2013) at the trial site location.

	2011-2012			2012-2013		
Month	T (°C)		Rainfall (mm)	T (°C)		Rainfall (mm)
	Maximum	Minimum		Maximum	Minimum	
September	20.4	11.3	22.5	17.7	7.9	109.4
October	16.8	9.2	47.5	13.1	5.7	56.8
November	12.4	6.5	59.3	9.9	2.8	82.5
December	9.3	2.9	91.9	7.7	1.5	117.0
January	8.8	1.9	57.6	6.2	2.3	60.2
February	7.3	0.9	21.3	6.3	0.3	58.5
March	13.3	3.4	19.4	6.0	-0.5	59.2
April	11.5	3	176.6	12.5	2.4	12.5
May	17.1	7.1	46.5	15.4	5.8	90.9
June	17.5	10.4	114.9	31	16.7	8.8
July	20	11.5	136.7	76.7	23.2	12.2
August	20.8	12.4	79.1	54.6	21.6	12.0
Average	14.6	6.7	72.78	21.43	7.48	56.67
Total			873.3			647.0

2.2. *Experimental design and treatments*

A 3x3 factorial design was used with randomized blocks and four replications. Each plot measured 4 m in width and 80 m in length. Each block contains 9 randomly allocated treatments as follows: 1). RTF Deep Tillage; 2). RTF Shallow Tillage; 3). RTF Direct Drill; 4). LGP Deep Tillage; 5). LGP Shallow Tillage; 6). LGP Direct Drill; 7). CTF Deep Tillage; 8). CTF Shallow Tillage; 9). CTF Direct Drill.

Differential trafficking intensities were applied to the plots (see Table 2) based on previous research which determined the intensity of in-field machinery passes, percentage of total wheeled area and number of repeated passes depending on the traffic and tillage system adopted (Kroulik et al., 2011). A 290 HP 12 tonne MF8480 tractor fitted with Michelin MachXbib tyres (600/70 R28 front and 650/85 R38 rear) were used to apply traffic to create differential levels of compaction found in the field under the different systems. Traffic intensities in the Random Traffic Farming and Controlled Traffic Farming treatments were applied using inflation pressures of 1.2 and 1.5 bar for the front and rear tyres respectively; for the Low Ground Pressure treatment both the front and rear tyres were inflated to 0.7 bar (Smith et al., 2013).

Table 2
Traffic intensities applied to plots including the number and percentage area covered by repeated passes and the total percentage wheeled area.

		Traffic											
		Random Traffic Farming				Low Ground Pressure				Controlled Traffic Farming			
		Number of repeated passes				Number of repeated passes				Number of repeated passes			
		1	2	3	Total	1	2	3	Total	1	2	3	Total
		Area covered by traffic (%)											
Tillage	Deep Tillage	15	30	30	86	15	30	30	86	0	30	0	30
	Shallow Tillage	30	30	0	65	30	30	0	65	0	30	0	30
	Direct Drill	15	30	0	45	15	30	0	45	0	30	0	30

The Deep Tillage plots were cultivated at a forward speed 8 km/h with rubber-tracked Cat Challenger MT765C and a 4 m Väderstad TopDown to a depth of 250 mm. The Shallow Tillage used the identical tractor and implement combination to a depth of 100 mm. Tilled plots (Deep Tillage and Shallow Tillage) were cultivated on 6th November 2012. The UK experienced an extremely wet summer and early autumn period in 2012, which resulted in a delayed drill date but still within the acceptable period in terms of crop variety. All plots were drilled into second winter wheat (*Triticum aestivum* var. *Duxford*) using the same 4 m Väderstad Rapid drill for all treatments (Deep Tillage, Shallow Tillage and Direct Drill). The same Cat Challenger MT765C used for cultivations was used for drilling. Sowing rates were based on breeders recommendations; 325 seeds m^2 at a row-spacing of 12.5 cm. Seed dressings of Beret Gold and Latitude were applied to combat fungal diseases including *Microdochium nivale* (snow mould), *Fusarium culmorum* (seedling blight, ear blight), *Septoria nodorum* (shriveled grains) and *Gaeumannomyces graminis* (take all), all of which are common risks in second wheat. All treatments received the same input levels of N, P, K and Mg fertiliser applications and were treated based on RB209 recommendations with the same post-emergence insecticide, herbicide and fungicide applications.

2.3. Crop establishment, growth and yield data

The effects of treatments on crop establishment were determined at GS11/12 when the first leaf had unfolded in January 2013. A quadrat method was used to determine the crop establishment (number of plants per metre squared) in the centre of each plot. A photographic assessment of crop growth on all of the plots was conducted throughout the growing season when the flag leaf was visible (GS37/39, May 2013) and again immediately before harvest. Plots were harvested at a forward speed of 5 km/h using a Claas Dominator 85 with a 4 m cutter bar on 31st August and 1st September 2013 at grain moisture content 14-16.5 %. Individual total plot yields (t/ha) were calculated by the weight of the grain removed by the combine harvester and adjusted to 14.5% grain moisture content (MC).

2.4. Statistical analysis

Data were analysed by a two-way analysis of variance (ANOVA) and Tukeys test in Genstat (15^{th} Edition).

3. Results and discussion

3.1. Site normalisation

Characterisation of variations in soil physical properties and crop growth and yield in Large Marsh was an essential process to inform the location of plot trials. This process, a rare opportunity in research, created a knowledge base of the local conditions against which treatment effects can be determined. A summary of the site assessment including soil texture, shallow and deep electrical conductivity and Normalised Vegetation Index (NDVI) is provided by Smith et al. (2013).

3.2. Crop establishment and growth

The interaction of traffic and tillage had no significant effect on the establishment of the number of winter wheat plants per square meter (p>0.05) (see Table 3). Throughout the growing season there was visual evidence to suggest non-uniform crop establishment in Direct Drill plots with limited growth in the primary wheelways (see Fig. 3a and 3b).

Table 3

Number of plants counted per metre squared in the centre of each plot, n=4, d.f. = 35.

		Traffic		
		Random Traffic Farming	Low Ground Pressure	Controlled Traffic Farming
Tillage	Deep	164	110	166
	Shallow	148	123	135
	Direct Drill	117	153	150

Fig. 3a. Photographs from Block 4 at GS 37/39 taken on 29th May 2013. The red and white ranging poles indicate the 4 m wide plots.

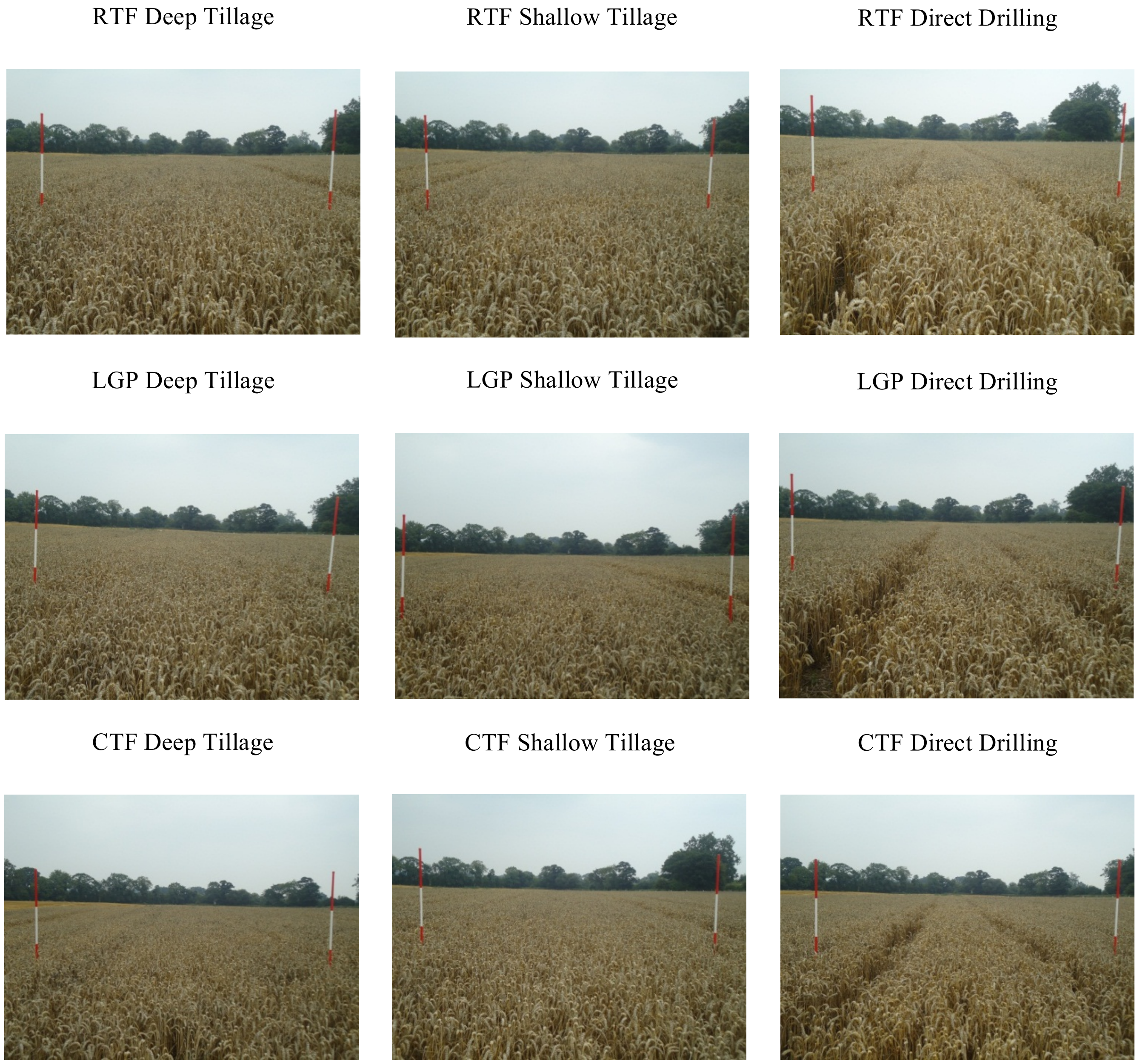

Fig. 3b. Photographs from Block 4 on 27th August 2013 before combine harvesting. The red and white ranging poles indicate the 4 m wide plots.

3.3. Yields

Mean combine harvested grain yields (t/ha) for all treatments from the first experimental year of the trial are presented in Figure 4. The interaction of traffic and tillage did not have a statistically significant effect on yield ($p>0.05$) (see Table 4).

The Controlled Traffic Farming treatments, regardless of tillage, yielded the highest with an average of 7.7 t/ha (±1 t/ha). The highest yielding treatment was the CTF Shallow Tillage with an average yield of 8.3 t/ha (±0.4 t/ha); a yield increase of 14% compared to an average of all other treatments (7.4 ±0.4 t/ha). The lowest yielding treatment was the Random Traffic Farming Direct Drill with an average of 6.8 t/ha (±0.5 t/ha). Tillage did have a statistically significant effect on yield ($p<0.05$) between the CTF Shallow Tillage treatment and Direct Drill treatments ($p<0.05$). Direct Drill treatments yielded the lowest regardless of which traffic system was adopted, with an average of

6.9 t/ha (±0.7 t/ha).

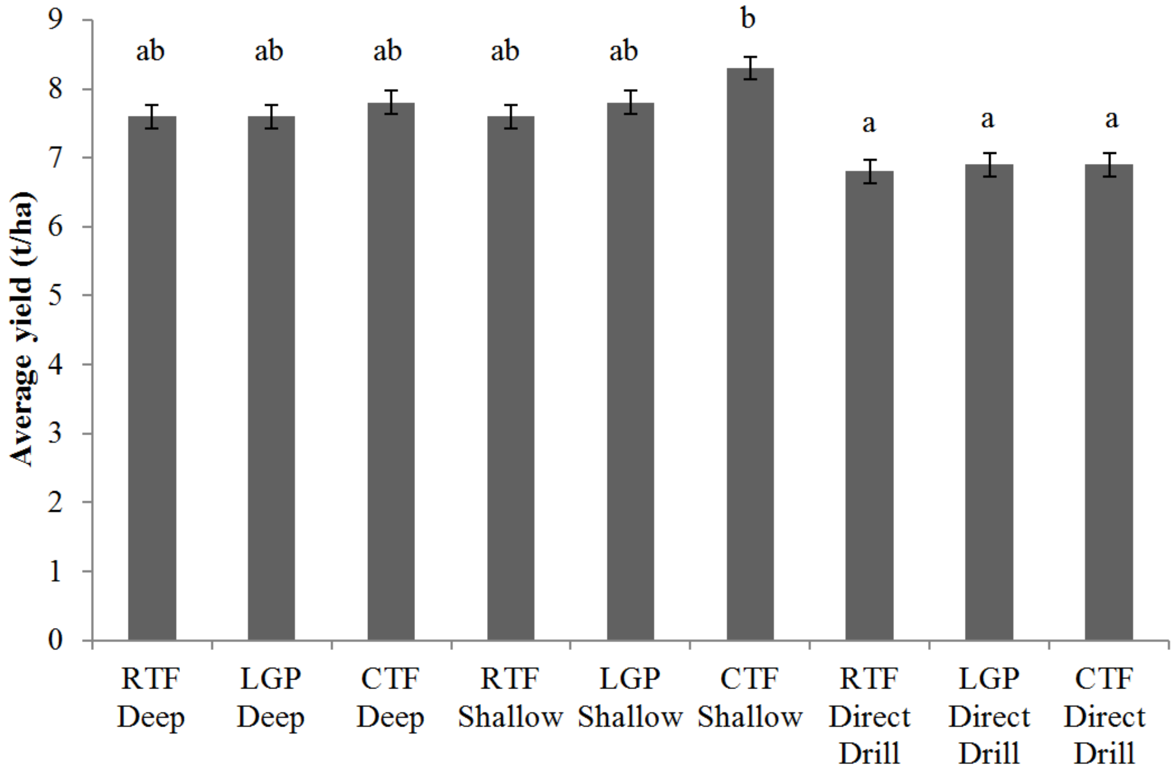

Fig. 4. Treatment effects on wheat grain yield (t/ha), n=4, d.f. = 35. Error bars show standard error. Statistically significant differences between treatments at 95% confidence are indicated by letters,

CTF is an alternative to conventional farming practices, i.e. RTF Deep, and produced a yield increase of 9%. This difference is not statistically significant ($p>0.05$) but equates to a cost benefit of approximately £103/ha (HGCA, 2013) based on yield increase alone: extra economic benefits can be achieved from savings in time and fuel. The plots used in this trial are 4 m wide. In a real-life situation, the working width of a CTF system would range from 6 to twelve meters, and therefore differences in yield from the plots needs to be extrapolated, taking into account the difference in trafficked and untrafficked yield in order to get a better understanding of the true benefits. Average yields from the RTF equivalent tillage treatments were used to estimate wheelway yields for CTF treatments. Average CTF yields for each tillage treatment were then used to calculate untrafficked yield to be extrapolated to the typical working widths found in commercial practice (see Table 4). These results will be validated in the future using hand harvested samples from the CTF plots which separate the trafficked and untrafficked areas.

Table 4

Potential yields (t/ha) using different CTF system working widths

	CTF system working widths (m)			
	6	8	10	12
Deep	7.93	7.98	8.00	8.02
Shallow	8.39	8.44	8.47	8.49
Direct Drill	6.95	6.96	6.97	6.97

The data presented in this paper indicates that increases in yield may be achieved in just one year by implementing Controlled Traffic Farming with any tillage system in comparison to conventional practice of Random Traffic Farming using either high or low inflation pressure tyres. In Australia where CTF has been most widely adopted, the greatest benefits for minimising run off, soil erosion, compaction and nutrient losses have been achieved using zero tillage (Tullberg et al., 2007). These systems have been used for a number of years, allowing for the benefits of using a Direct Drill to become established. It is important to consider the whole farming system over the longer time scale, and that benefits achieved with alternative tillage systems may not be initially evident. Furthermore, timeliness is an important consideration when implementing tillage systems (Tullberg et al., 2007). The current study conducted all field operations for the different treatments on the same day, i.e all plots were cultivated on the same date as each other, and all plots were drilled on the same date as each other. A further study in the UK and Australia will consider the benefits and limitations associated with on-farm application, including timeliness of operations within different systems.

4. Conclusions

1. A uniform trial site has been established to investigate the interaction of traffic and tillage and provide a long-term facility for taking soil, crop and energy measurements;
2. There was no statistically significant difference in early crop establishment as a result of traffic and tillage. Visual differences became detectable as the growing season progressed, with limited establishment of crops in the primary wheelways of Direct Drill treatments;
3. CTF treatments yielded the highest on average. There was no statistically significant difference in harvestable yield as a result of traffic and tillage;

5. Further Work

The effects of the treatments presented in this paper will be investigated over the next ten years or more and coupled with further soil, crop and energy parameters (fuel consumption and draught force requirement) will deliver long-term information on the effect of the interaction of traffic and tillage.

Acknowledgements

The authors gratefully acknowledge the assistance of Challenger, Väderstad and Michelin for their support in their expertise and the loan of equipment for this study. This study is funded by the Douglas Bomford Trust and Harper Adams University.

References

Alakukku, L., Weisskopf, P., Chamen, W.C.T., Tijink, F.G.J., van der Linden, J.P., Pires, S., Sommer, C., Spoor, G. 2003. Prevention strategies for field traffic-induced subsoil compaction: a review Part 1. Machine/soil interactions. Soil and Tillage Research. 73, 145-160.

Chamen, T., Alakukku, L., Pires, S., Sommerd, C., Spoor, G., Tijink, F., Weisskopf, P. 2003. Prevention strategies for field traffic-induced subsoil compaction: a review. Part 2. Equipment and field practices. Soil and Tillage Research. 161-174.

Chamen, T. 2011. The effects of low and controlled traffic systems on soil physical properties, yields and the profitability of cereal crops on a range of soil types. PhD thesis. Cranfield University, School of Applied Sciences.

Chen, H., Yang. Y. 2013. Effect of Wheel Traffic and Tillage on Soil Water Infiltration in Annual Two-crop Region of Northern China Plain. Frontiers in Environmental Engineering. 2, 24-29.

Chyba, J. 2012. The influence of traffic intensity and soil texture on soil water infiltration rate. MSc diss. Harper Adams University, Department of Engineering.

Fitzpatrick, E. A. 1991. An introduction to soil science 2. John Wiley & Sons, New York.

Forth, H. D. 1978. Fundamentals of soil science. John Wiley and Sons, New York.

Gerrard, J. 2000. Fundamentals of soils. Routledge.

Hamza, M.A., Anderson, W.K. 2005. Soil compaction in cropping systems. A review of the nature, causes and possible solutions. 82, 121-145.
HGCA. 2013. Market Report 16 September 2013, Volume 8 Issue 12. Website accessed 23/09/2013. Available at: http://ahdb.cmail2.com/t/ViewEmail/r/68C509757DD471F52540EF23F30FEDED/03CDA3EDED4D08E5405DC10595964AA8
Kingwell, R. and Fuchsbichler, A. 2011. The whole-farm benefits of controlled traffic farming: An Australian appraisal. Agricultural Systems. 104, 513-521.
Koga, N., Tsuruta, H., Tsuji, H., Nakano, H. 2003. Fuel consumption-derived CO_2 emissions under conventional and reduced tillage cropping systems in northern Japan. Agriculture, Ecosystems and Environment. 99, 213-219.
Kristof, K. 2012. Establishment of a long term experiment into tillage and traffic management. Part Two: Evaluation of spatial heterogeneity for the design and layout of experimental sites. Proceedings of the International Conference of Agricultural Engineering 8-12 July. Valencia, Spain.
Kroulik, M., Kumhala, F., Hula, J. and Honzik, I. 2009. The evaluation of agricultural machines field trafficking intensity for different soil tillage technologies Soil & Tillage Research. 105, 171-175.
Kroulik, M., Kviz, Z., Masek, J. and Misiewicz, P. 2011. Benefits of GPS agricultural guidance for Sustainable agriculture. Proceedings of the 19th ISTRO Conference 24 - 28 September 2011. Uruguay.
Lamande, M. and Schjonning, P. 2011. Transmission of vertical stress in a real soil profile: Part II: Effect of tyres size, inflation pressure and wheel load. Soil and Tillage Research. 114, 71-77.
Lipiec, J., Kus, J., Slowinska-Jurkiewicz, A., Nosalewicz, A. 2006. Soil porosity and water infiltration as influenced by tillage methods. Soil and Tillage Research. 89, 210-220.
Munkholm, L. J., Schjonning, P., Rasmussen, K. J. and Tanderup, K. 2003. Spatial and temporal effects of direct drilling on soil structure in the seedling environment. Soil and Tillage Research. 71, 163-173.
Rowell, D. L. 1994. Soil science: methods and applications. Longman, UK.
Silburn, D. M. and Glanville, S. F. 2002. Management practices for control of runoff losses from cotton furrows under storm rainfall, I. runoff and sediment on a black vertosol. Australian Journal of Soil Research. 40, 1-20.
Sip, 2013. Winter wheat yield and quality related to tillage practice, input level and environmental conditions. Soil and Tillage Research. 132, 77-85.
Smith, E.K., Misiewicz, P.A., Chaney, K., White, D.R., Godwin, R.J. 2013. An investigation into the effect of traffic and tillage on soil properties and crop yields. Proceedings of the 2013 Annual International Meeting 21-24 July. Kansas City, Missouri.
Spoor, G., Tijink, F.G.J., Weisskopf, P. 2003. Subsoil compaction: risk, avoidance, identification and alleviation. Soil and Tillage Research. 73, 175-182.
Trethowan, R.M., Mahmood, T., Ali, Az., Oldach, K., Garcia, A.G. 2012. Breeding wheat cultivars better adapted to conservation agriculture. Field Crops Research. 132, 76-83.
Tullberg, J. N., Yule, D. F. and Mcgarry, D. 2007. Controlled traffic farming - From research to adoption in Australia Soil and Tillage Research, 97 272-281.
Tullberg, J. 2010. Tillage, traffic and sustainability. A challenge for ISTRO. Soil and Tillage Research. 111, 26-32.
Voorhees, W. B. and Lindstrom, M. J. 1984. Long-term effects of tillage method on soil tilth independent of wheel traffic compaction. Soil Science Society of America. 48, 152-156.