Summary of the effects of three tillage and three traffic systems on cereal yields over a four-year rotation

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Summary

This paper reports the design and results of a study to consider the effects of deep, shallow and zero tillage with random conventional and low tyre inflation pressures and controlled traffic systems on the yield of winter wheat, winter barley (×2) and spring oats. The results show that crop yields for zero tillage were significantly less ($P<0.001$) than deep and shallow tillage for all crops with an overall reduction of 1.0 t/ha below the mean of the deep and shallow tillage practices. Controlled traffic farming with a 30% trafficked area produced significantly higher yields than random conventional pressure traffic for the winter wheat and spring oats. Controlled traffic farming, with trafficked areas of 30% and 15% showed overall benefits over random conventional inflation pressure traffic of 0.32 t ha^{-1} (£41 ha^{-1}) and 0.61 t ha^{-1} (£77 ha^{-1}) respectively, requiring breakeven areas of 312 ha and 168 ha to cover the costs of 3 vehicle guidance/auto-steering systems.

Key words: tillage, random and controlled traffic, cereal yield.

Introduction

Work in Scotland (Soane, 1970) showed that approximately 90% of a field growing spring barley was covered by wheel marks during the crop establishment operations. Using global positioning system-tracking devices Kroulik *et al.* (2009) revealed that random traffic farming (RTF) practices, with conventional tyre inflation pressures, for wheat production covered some 86%, 65% and 45% of the field with at least 1 wheel pass for conventional (plough based) tillage, minimum tillage and direct drilling/zero-till respectively. This then suggests that much could be gained from controlled traffic farming (CTF) practices where field operations are focused on predetermined wheel-ways, and equipment widths and wheel track spacing are matched. This is now made easier with the use of real time kinetic (RTK) global positioning satellite guidance and auto-steer systems.

The potential advantages through avoiding compaction from this practice are:

1. Improved crop yields, which will be the main focus of this paper.
2. Reduced tillage and crop establishment draught forces/energy.
3. Improved soil conditions and infiltration of rainfall/irrigation water.

These are achievable providing that the mechanisation systems permit matching of the equipment operating width and wheel centre spacing. An alternative to CTF is the use of lower tyre inflation (ground) pressure systems (LGP), which has become more practical for higher power tractors with the introduction of Ultra-Flex tyres (Michelin). These tyres can operate at inflation pressures down to 0.4 bar for very low loads. However, where a tractor equipped with conventional tyres inflated to 1.2 bar and 1.5 bar for the front and rear tyres respectively the recommended inflation rate for ultra-flex tyres is typically 0.6 to 0.7 bar.

Chamen (2011) reported yield improvements between 7% and 35% for CTF systems for a range of crops in a number of different international studies. This data is very promising, however, not all of the results were from replicated experiments and soil compaction, if present, was not reported as being alleviated by soil loosening prior to the initiation of the work. In order to overcome these issues randomized, replicated studies were initiated by Cranfield University and The Arable Group (TAG) in 2007 and 2009; the Slovak University of Agriculture in 2010; and Harper Adams University, Newport, Shropshire, UK in 2011 (Godwin *et al*., 2015). The studies conducted by Cranfield University/TAG at Morley demonstrated winter wheat yield improvements from CTF for two tillage depths (shallow 50–150 mm and deep 150–250 mm) of 15.5% and 16.4% respectively and a 12% and 5.5% improvement where the machinery operations were confined to a rubber-tracked vehicle.

Galambosova *et al*. (2017) reported that in Slovakia where a 16 ha field was managed using 6.0 m wide CTF systems with three 33 m wide compacted (RTF) zones crossing the direction of the CTF traffic, that CTF showed advantages over the RTF for three crops/seasons. Spring barley showed the greatest difference (50%, P=0.05)), followed by maize (32.5%, P=0.15) and winter wheat (10%, P=0.1).

With the exception of the work at Morley, the remainder of the work reported above was undertaken with one depth of tillage system without particular attention to the underlying soil conditions. In order to determine the effects of tillage depth (250 mm, 100 mm and zero-till) and traffic systems, a long-term experiment (*c*.10 years) was established by Harper Adams University in 2011. The effect of LGP using Ultra–Flex tyres were studied in addition to the RTF and CTF traffic systems.

Materials and Methods

A very slightly stony sandy loam (Claverley series) field was chosen for this study, which was drained at 13 m spacing and subsoiled to a depth of 0.5 m to remove deep compaction. The site had a topsoil pH 6.6 and subsoil pH 6.1. In order to locate an area of the field with the minimum heterogeneity for the experiment, both conventional soil mapping and electromagnetic resonance techniques were used. Following this, a winter wheat crop was established in forty 80 m long by 4.0 m wide plots with 0.6 m wide wheel tracks at a wheel centre spacing of 2.1 m. Plot widths of 4.0 m were chosen to keep the experiment within the uniform soil zone and match the readily available complement of field machines; this resulted in a trafficked area for the CTF plots of 30% of the total area. This figure should be relatively easy for farmers to achieve.

Variable traffic and tillage treatments were not applied in the first season, the site was allowed to “recover” from the pre-treatments and the spatial uniformity of the proposed plot-treatment zones determined following ploughing with a 4 m wide mould-board plough and power harrow/drill combination with the wheel tracks set at those for the CTF operations in subsequent years (Smith *et al*., 2013; Smith, 2016).

The plots yields were harvested using a combine harvester with a 4.0 m wide cutter-bar equipped with a yield monitoring device and the total yield/plot weighed. The coefficient of variation of the wheat yield of the proposed experimental site was 6.0%. Following these results 36 contiguous treatment plots were chosen in four randomised complete blocks from the 40 plots to determine the relative effects of three traffic management systems, namely:

1. Random traffic farming (RTF) with conventional (1.2 and 1.5 bar) inflation pressure in the front and rear tractor tyres respectively.
2. Lower ground pressure farming (LGP) with lower (0.7 bar) inflation pressure in both the front and rear tractor tyres and
3. Controlled traffic farming systems (CTF).

These traffic effects were combined with 3 tillage treatments in a 3 × 3 factorial design, namely: (1) Deep tillage (250 mm), (2) Shallow tillage (100 mm) and (3) Zero tillage.

The traffic treatments were installed in the autumn of 2012, 2013, 2014 and 2015 following the traffic intensity patterns (both area and number of passes) of the tillage system reported by Kroulik *et al*. (2009). Both the deep and shallow tillage was conducted using 4.0 m wide combination (conical disc/rigid tine/press) tillage tool (Vaderstad Topdown) to cut surface residues, mix, loosen, level and reconsolidate the soil, to provide a suitable tilth for the establishment of the cereal crop following seed placement. In 2012 a "single disc" drill (Vaderstad Rapid) was used for seed placement in all treatments; an "offset V disc" drill (Vaderstad Spirit) replaced this in 2013–2016, as this was more suitable for the soil conditions. The rotation consisted of winter wheat (Duxford) (2012–3), winter barley (Cassia) (2013–4 and (2014–5), a winter cover crop (Terralife N-Fix) (2015–6) followed by spring oats (Aspen) (2016).

Hand harvested grain yield subsamples, for a length of 0.3 m were collected from the trafficked and non-trafficked areas of the CTF plots (Table 1) prior to recording the crop yields of the whole plots using the 4.0 m wide combine harvester (Table 2). The hand-harvested data was particularly important in assessing the effects of the traffic zones, especially with the CTF treatments as this enabled the combine harvester yields to be estimated for a CTF system with a traffic lane area of *c*.15% (typically 12 m wide controlled traffic systems with 1.8 m wheel/track trafficked widths) which could further improve crop yields and is the aim of many CTF farmers. These estimates are given in the right hand column of Table 2. The draught force and fuel consumption of the subsequent tillage and drilling operations were recorded at 8.0 km h^{-1}, using a tension dynamometer and positive displacement fuel meter.

Results

The yield data for the main effects of the hand harvested grain in Table 1 show that the yield in the traffic lane of the CTF treatments is significantly less (P=0.03, 0.01, 0.004 and 0.001 respectively) for all years/crops than that of the non-trafficked zone and that tillage has no effect on the mean yield. The effect of traffic reduces the mean yield by 2.90, 1.78, 2.03 and 1.44 t ha^{-1} for each of the 2013 to 2016 harvest dates; these are equivalent to a 31%, 22%, 17% and 18% respectively. Closer observation shows that there was a 6.08 t ha^{-1} difference in the winter wheat yield in 2013 of the zero tillage treatments where the traffic lane effects resulted in a yield of 4.34 t ha^{-1} whilst the non-trafficked zone was higher than all other treatments at 10.72 t ha^{-1}. The magnitude of this differential was not repeated in subsequent years and could be due to the choice of the available drill and/or the very wet soil conditions at crop establishment in 2012. There was, however, a 2.32 t ha^{-1} (28%) reduction in the yield of spring oats in the zero tillage treatments in 2016 from the effect of wheel traffic.

Table 1. *Hand harvested yields (t ha^{-1}) in the traffic lanes and non-trafficked zones of the controlled traffic system plots. Means not followed by the same letter are significantly different at 5% probability. (Smith* et al.*, 2013; Smith, 2016; Millington* et al.*, 2016, Millington, 2016* pers. comm*).*

	Traffic lane	Non-trafficked	Mean
Winter Wheat 2013		Traffic LSD$_{5\%}$ =1.78	
Deep Tillage	7.69	8.97	8.33a
Shallow Tillage	7.04	8.10	7.57a
Zero Tillage	4.34	10.72	7.53a
Mean	6.36a	9.26b	
Winter Barley 2014		Traffic LSD $_{5\%}$ =1.27	
Deep Tillage	6.06	8.69	7.37a
Shallow Tillage	6.22	7.68	6.95a
Zero Tillage	6.79	8.06	7.42a
Mean	6.36a	8.14b	
Winter Barley 2015		Traffic LSD $_{5\%}$ =1.26	
Deep Tillage	9.87	13.24	11.55a
Shallow Tillage	10.69	12.53	11.61a
Zero Tillage	10.00	10.90	10.45a
Mean	10.19a	12.22b	
Spring Oats 2016		Traffic LSD$_{5\%}$ = 0.75	
Deep Tillage	7.33	8.33	7.83a
Shallow Tillage	7.01	8.00	7.51a
Zero Tillage	5.87	8.19	7.03a
Mean	6.73a	8.17b	

The yield data for the main effects of the combine harvested grain given in Table 2 show:

1. The mean yields from the zero tillage treatment were significantly less (P<0.001) than those from the deep and shallow tillage for the winter wheat (2013), winter barley (2015) and spring oats (2016). There was no significant yield difference (P=0.857) between the different tillage systems for the winter barley yield in 2014. Although not significantly different, the yields from the shallow tillage treatments were marginally higher than those from the deep tillage treatments in each year of the study, agreeing with the 14 year average of wheat yields reported by Dawkins (2014) from data from commercial farms.
2. The mean yield from controlled traffic treatments (CTF$_{30\%}$ for the 30% trafficked area) were significantly higher than the yield from the random traffic treatments for both the winter wheat (2013 (0.5 t ha^{-1}) P=0.073) and spring oats (2016 (0.55 t ha^{-1}) P=0.057), with the yield of the low ground pressure system positioned approximately mid-way between them but not significantly different from either. There were no significant differences in the effects of traffic for the winter barley yield in both 2014 (P=0.682) and 2015 (P=0.84).
3. The probability level of 0.073 for the effects of traffic was considered acceptable for practical agriculture, because when this data was combined with that of similar studies using the method developed by Fisher to combine probabilities (Sokal & Rohlf, 1981) with p values ranging from 0.05 to 0.1 the resulting combined probability lay between 0.01 and 0.001 (Godwin *et al.*, 2015).
4. There was no significant interaction between the effects of tillage and traffic for any crop/season.

Table 2. *Combine harvested yields (t ha^{-1}) for a range of tillage and traffic systems. Means not followed by the same letter are significantly different at the quoted probability level. The right hand column shows the estimated yields for controlled traffic systems with a traffic lane area of 15%. (Smith* et al.*, 2013; Smith, 2016; Millington, 2016* pers. comm*).*

	Random Traffic RTF	Low Ground Pressure LGP	Controlled Traffic CTF$_{30\%}$	Mean	Controlled Traffic CTF$_{15\%}$
Winter Wheat 2013	Traffic and Tillage LSD$_{10\%}$= 0.35				
Deep Tillage	7.29	7.71	7.93	7.65b	8.11
Shallow Tillage	7.67	7.93	8.39	8.00b	8.56
Zero Tillage	6.87	7.02	7.01	6.97a	7.78
Mean	7.28a	7.55ab	7.78b	7.54	8.15
Winter Barley 2014	No significant difference				
Deep tillage	8.50	8.50	8.50	8.50a	8.92
Shallow Tillage	8.60	8.20	9.10	8.63a	9.37
Zero Tillage	8.80	8.60	8.40	8.60a	8.61
Mean	8.63a	8.43a	8.67a	8.58	8.97
Winter Barley 2015	Tillage LSD$_{5\%}$ = 0.69				
Deep Tillage	11.17	11.46	11.53	11.39b	11.93
Shallow Tillage	11.53	11.61	11.40	11.51b	11.67
Zero Tillage	9.93	9.99	10.28	10.07a	10.41
Mean	10.88a	11.02a	11.07a	10.99	11.34
Spring Oats 2016	Traffic and Tillage LSD$_{5\%}$ = 0.46				
Deep Tillage	8.61	8.96	9.12	8.89b	9.28
Shallow Tillage	8.81	8.86	9.06	8.91b	9.23
Zero Tillage	6.70	6.91	7.60	7.07a	7.95
Mean	8.04a	8.24ab	8.59b	8.29	8.82

Table 2 also shows the estimated crop yield for a CTF$_{15\%}$ system. This data was estimated by re-proportioning the whole plot CTF$_{30\%}$ yield in Table 2 using the relative yields of the trafficked and non-trafficked zones from the data in Table 1 for each of the tillage systems. The mean yield for the three tillage systems for each crop/year shows a 4.8%, 3.5%, 2.4% and 2.7% yield improvement over CTF$_{30\%}$ with a mean improvement of 3.4%.

Yield comparison between the CTF$_{15\%}$ and the RTF for the deep and shallow tillage systems (not including zero-tillage as this had a significantly lower yield than the other tillage systems in 3 of the 4 years) shows that CTF$_{15\%}$ produced annual yield improvements of 0.86 t ha^{-1} (11.4%), 0.6 t ha^{-1} (7%), 0.45 t ha^{-1} (4.0%) and 0.55 t ha^{-1} (6.3%) respectively.

The mean annual yield and the mean annual value of the crops for the 4 years data is given in Figure 1 for the tillage systems (upper) and traffic systems (lower). The mean annual value is based upon the November 2016 grain prices from AHDB Cereals and Oilseeds of wheat at £140 t^{-1}, barley £110 t^{-1} and oats £125 t^{-1}. The tillage data show that the differences between the zero tillage treatments and that of the mean of the shallow and deep tillage systems are at 1.0 t ha^{-1} and £124 ha^{-1}. Similarly, LGP systems show a small overall benefit of 0.1 t ha^{-1} and £15 ha^{-1} over the RTF system. The CTF$_{30\%}$ and CTF$_{15\%}$ show yield benefits of 0.32 t ha^{-1} and 0.61 tha^{-1} and economic benefits of £41 ha^{-1} and £77 ha^{-1} respectively.

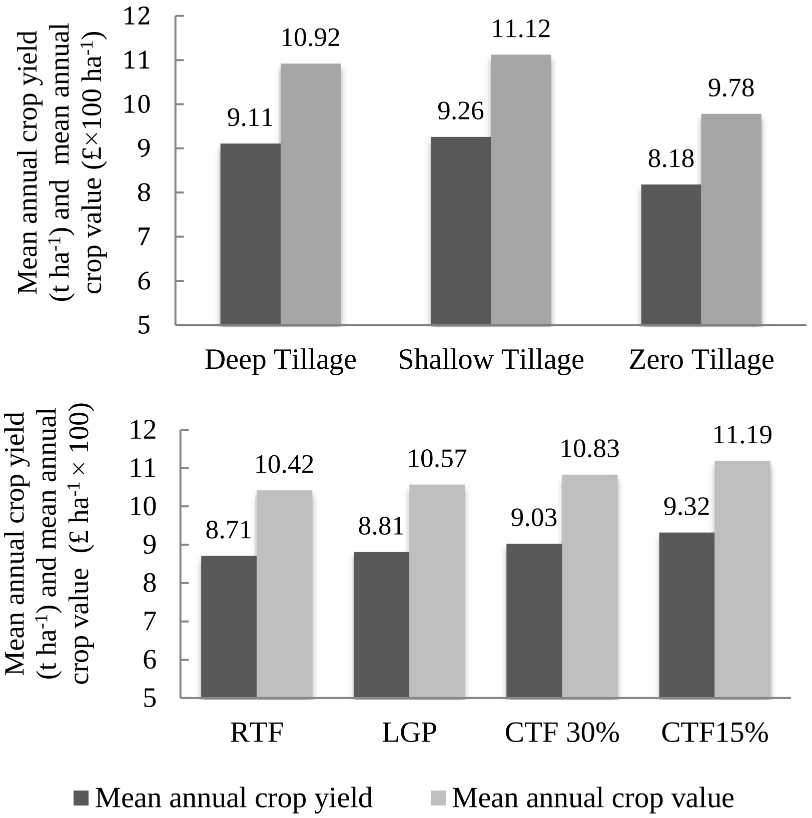

Fig. 1. Overall effect of tillage (upper) and traffic (lower) systems on mean annual yields and mean annual crop value for the four experimental seasons.

Assuming that a farmer or contractor contemplating CTF would initially use existing equipment and that improvements to equipment matching would be part of the normal longer-term replacement policy the main additional cost would, therefore, be the investment in vehicle guidance/auto-steering systems. Following the procedures undertaken by the authors, reported in Hargreaves *et al*. (2017), the annual cost of a single high accuracy, RTK (+/- 20 mm) fully integrated vehicle guidance system; based upon a capital cost of £15,000 and an annual RTK subscription fee of £500 year^{-1} with: interest rates of 4.5%, depreciation of 15%, maintenance of 5% and training of £100 year^{-1} (Nix, 2015) is £4275. The cost per ha is given in Fig. 2. This shows that the cost declines for a range of harvest areas from £85 ha^{-1} for 50 ha to £4.3 ha^{-1} for 1000 ha. Comparing the £41 ha^{-1} and £77 ha^{-1} CTF benefits over RTF with the curve in Fig. 2. gives breakeven areas of 104 ha and 56 ha for the implementation of CTF systems. In practice a number of guidance systems would be required to support the tractors, combine harvester and other associated field equipment required for CTF. Hence if three systems were required the breakeven areas would increase to 312 ha and 168 ha for CTF$_{30\%}$ and CTF$_{15\%}$ respectively.

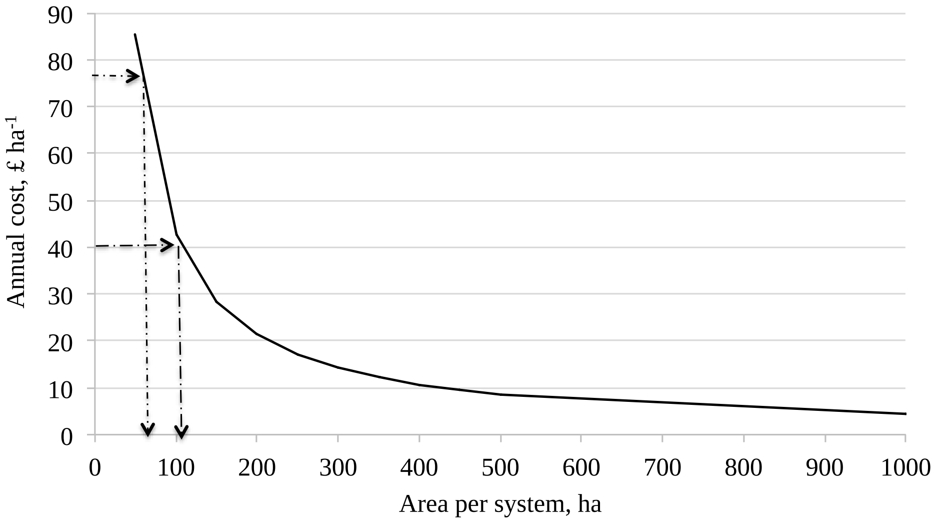

Fig. 2. Break even comparisons of the mean annual economic benefits of $CTF_{30\%}$ (long dash - dot line) and $CTF_{15\%}$ (short dash – dot line) over RTK with the annual cost of operation of a high accuracy (RTK), fully integrated steering vehicle guidance system (solid line).

The draught forces and fuel consumption of the tillage and drilling operations at a speed of 8.0 km h^{-1} in 2013 were recorded (Arslan *et al*. 2014) and are presented in Table 3. The data showed significant ($P < 0.05$) differences in the tillage operations but no difference in draught force of the drill and the traffic systems (not shown). Also given are the fuel costs at £0.50 l^{-1}.

Table 3. *Mean draught forces, fuel consumption and fuel costs at £0.50* l^{-1} *for the 3 tillage systems. Means not followed by the same letter are significantly different (P<0.05). Arslan* et al.*, 2014.*

Treatment	Tillage draught force, kN	Drill draught force, kN	Fuel consumption tillage and drill, l ha^{-1}	Fuel cost £ ha^{-1}
Deep tillage, 250 mm	64.9a	15.9a	22.16a	11.08a
Shallow tillage, 100 mm	21.3b	16.7a	16.42b	8.21b
Zero-till	00.0c	16.5a	8.82c	4.41c

Discussion

The reduced yields from the zero-tillage treatments was disappointing as many farmers are looking to this technique to reduce the time and costs of tillage operations (Godwin, 2014). However, it was not unexpected as the data given by Cannell, (1978) and Soane *et al*., (2012) would suggest that the climatic conditions are not ideal for zero tillage in the wetter western parts of the UK. Improvements to the soil conditions in the wheel-ways, by a shallow wheel mark eradication operation, especially in the 2012–13 season could have been of benefit. The longer term expected recovery for crop yields grown using zero tillage as suggested by Carter (1994) did not materialize, although zero tillage gave comparable yields to the other tillage systems in the winter barley in 2013–14.

Overall the CTF system performed well, giving yield improvements at levels for most practical farmers to consider the adoption of the practice. The estimated yield improvement for CTF systems with a trafficked area of 15% demonstrates the benefit the lower trafficked area systems. The results are not as high as some of those reported in earlier studies by Chamen (2011) and Galambosova *et al*. (2016) but are economically viable.

Breakeven areas of 312 ha and 168 ha may appear high to farms with smaller cropped areas; the adoption of less accurate vehicle guidance/auto-steering systems with a capital cost of circa £5000 reduces the annual costs to £1325 system (Hargreaves *et al*., 2016) and result in breakeven areas of 97 ha and 52 ha respectively for three systems.

Reducing the tyre inflation pressure of the random traffic system, in the two seasons where the traffic system had a significant effect, resulted in crop yields that lay approximately mid-way between the random traffic (with higher inflation pressures) and the controlled traffic system with a trafficked area of 30%. The relative benefit of this in comparison with those of the other systems, alongside the fuel consumption data, will be of importance when undertaking a full economic evaluation.

Conclusions

1. Crop yields for the zero tillage treatments were significantly less (P<0.001) than deep and shallow tillage for winter wheat, winter barley and spring oats in 2013, 2015 and 2016 respectively. Albeit the hand harvest data for the 2013 winter wheat showed a significant improvement in yield in the non-trafficked areas. Integrating all the tillage data shows that zero-till yields were 1 t ha^{-1} and £124 ha^{-1} below the mean of deep and shallow tillage.
2. The overall the effect of traffic in the CTF plots significantly (P=0.03, 0.01, 0.004 and 0.001 for each year respectively) reduced the yield in the trafficked lane by between 1.44 t ha^{-1} and 2.90 t ha^{-1} or 17% to 31% from that of the non-trafficked zone.
3. The controlled traffic farming system with a 30% trafficked area had a significantly higher yield over RTF for the winter wheat (P=0.073) and spring oats (P=0.057) in 2013 and 2016 respectively but were not significantly different in the two winter barley crops. The grain yields from the low ground pressure traffic management system are approximately mid-way between them.
4. Reducing the trafficked area from 30% to 15% increased the 4 year mean yield by 3.4%. The CTF$_{30\%}$ and CTF$_{15\%}$ show benefits over RTF of 0.32 t ha^{-1} and 0.61 t ha^{-1} equivalent to £41 ha^{-1} and £77 ha^{-1} respectively.
5. The breakeven areas to cover the additional costs of three RTK vehicle guidance systems at 2016 grain prices are 312 ha and 168 ha for CTF$_{30\%}$ and CTF$_{15\%}$ respectively.
6. The draught forces and fuel consumption of the tillage and drilling operations showed significant (P<0.05) differences between the depth of the tillage operations but no significant difference in the draught force and fuel consumption for the drilling operation and the different traffic systems.

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