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Effect of controlled traffic farming on energy saving in Australian grain cropping systems

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ABSTRACT. *Controlled traffic farming (CTF) is a system in which all machinery has the same or modular working and track widths so that field traffic can be confined to the least possible area of compacted permanent traffic lanes. In well-designed CTF systems permanent traffic lanes usually occupy less than 15% of cropped area, and this has been widely adopted in Australia. CTF is a practical and cost-effective facilitator of no-tillage farming, and the basis for more precise cropping systems. Controlled traffic systems are often claimed to reduce power and fuel requirements of cropping operations, because motion resistance to traffic should be less on permanent lanes, and draft requirement of tilling or seeding should be less in non-compacted soil. Experimental work was conducted to assess the effects of tractor wheel compaction on the energy requirements of soil-engaging operations, particularly, during tillage and planting. Preliminary results from this investigation indicate that on average the draft of tillage sweeps, planter openers, and chisel tines increased by approximately 35%, 37%, and 54%, respectively, when positioned behind a tractor wheel.*

Keywords. *Controlled traffic farming, Draft, Soil compaction, Soil engaging implements, Tillage energy.*

Introduction

The cost of soil compaction in Australia has been estimated to be ≈AUD850M per year (AUD1 ≈ USD0.75) in terms of production loss (Walsh, 2002). There are also additional and significant, although less quantified costs associated with tillage repair treatments as well as on- and off-farm environmental impacts. Controlled traffic farming (CTF) systems manage compaction by confining all load-bearing wheels to the least possible area of permanent traffic lanes (Taylor, 1983). In well-designed grain-cropping systems, permanent traffic lanes typically occupy ≤15% of the total cultivated area (Tullberg, 2010). Without CTF, multiple equipment operating and track widths translate into disorganized or random traffic patterns. These can cover about 50% crop area in no till systems, and up to 80% of the cultivated area each time a crop is produced (Kroulík et al., 2009). Research has shown that CTF systems have advantages in maintaining 'good' soil structural conditions with lower inputs of energy (reduced draft), improved trafficability and timeliness compared with conventional traffic systems (e.g., Tullberg, 2000; McHugh et al., 2009). In Australia, CTF represents a profitable technological innovation for arable land-use (Kingwell and Fuchsbichler, 2011) and has additional agronomic and environmental benefits (Tullberg, 2010), including reduced potential for greenhouse gas (GHG) emissions (Antille et al., 2015) and enhanced fertilizer-use efficiency (Hussein et al., 2017). Adoption of CTF by Australian grain growers is estimated to be approximately 25% (Edwards et al., 2012).

In a CTF system, the crop zone and the traffic lanes are distinctly and permanently separated. In practice, this means that the working widths of all implements fit a modular system, and all wheel tracks are confined to specific traffic lanes (Isbister et al., 2013). Adoption of such systems should (1) minimize traffic-induced soil compaction and therefore tillage draft, (2) optimize crop growth conditions within non-compacted permanent beds, and (3) improve traction on compacted permanent traffic lanes (Burt et al., 1986; Chen and Yang, 2015). Energy requirements for tillage in soil subject to random (uncontrolled) machinery traffic is also significantly greater compared to CTF (Carter, 1985; Tullberg, 2000). These benefits suggest a growing need for adoption of CTF systems, but this has been slowed by factors such as incompatible equipment operating and wheel track widths. Associated costs of equipment conversion, concern about warranties and the resale value impacts have also inhibited widespread adoption of CTF in some cropping systems (Tullberg et al., 2007; Chamen, 2015).

In Australia, previous CTF research has focused primarily on agronomic and environmental benefits associated with adoption of these systems (e.g., Li et al., 2007). There appears to be little scientific-based evidence of the impacts of CTF on energy requirements for tillage on Australian cropping systems, with some exceptions such as the work of Tullberg (2000). This study showed that the traffic effect of wheels on the draft of tillage implements increased total draft by 30% or more compared with the same implement operated in non-trafficked soil. The same work also indicated that about 50% of a tractor's power output may be dissipated in the process of creating and disrupting its own wheel compaction. Tullberg (2010) used these observations to explain the potential reduction in tillage energy that occurs in CTF systems. As a reference, estimates of (average) fuel usage for tillage operations are in the range of 7 to 12 L ha^{-1} (Tullberg, 2000). Studies conducted at Harper Adams University in the United Kingdom (Arslan et al., 2015; Godwin et al., 2015) showed relatively small benefits of CTF in terms of reduced draft force, possibly due to data collected after only two years following establishment of a dedicated CTF experimental site. However, greater benefits may be realized in the longer-term. In a related study at the same experimental site in the U.K., Smith et al. (2014) found that soil physical properties were significantly improved by the traffic system, thus yields have increased in all tillage systems under CTF. Compaction increases bulk density and soil strength (Ayers and Perumpral, 1982). This is directly related to energy requirement of tillage implements, including equipment for sowing and weeds management operations, but evidence of the impact of CTF on energy use is still limited. The objective of the work reported in this paper is to demonstrate and assess the effects of tractor wheel compaction on energy requirements of soil-engaging operations, particularly tillage and seeding.

Materials and Methods

Experimental Site

The experimental site is located in Felton, Queensland, Australia (-27°49'38" S, 151°45'54" E), and has been under controlled traffic and no-tillage for approximately 15 years (Figure 1).

Figure 1. Experiment field located in Felton (-27°49’38” S, 151°45’54” E), Queensland, Australia.

The soil at the site is described in Isbell (2002) as a Black Vertisol. Soil physical properties measured at the site are shown in Table 1 and Figure 2, respectively. Penetration resistance was recorded by a handheld Rimik Model CP20 penetrometer to a depth of 500 mm, based on ASAE Standards (1999). Moisture content was also measured to the same depths, while the bulk density (g cm^{-3}) and shear force (MPa) were measured in the 0-150 mm depth interval, which reflects the tillage depth assessed in this study. The experiment was conducted in permanent crop beds (CB) of a 550-m × 15-m plot arranged in a complete randomized block design, with three replications (n=3). Two factors and three levels of comparison, namely: working depth (75, 100, and 125 mm, respectively) and type of tine (chisel, sweep, and planter opener, respectively) were used. The working depths were chosen to represent those commonly used in Australia for planting and fertilizer application, shallow tillage, and deep placement of fertilizer, respectively. Shallow tillage is occasionally conducted in long-term no-tillage soil for control of glyphosate-resistant weeds (Dang et al., 2017; Melland et al., 2017), as well as seedbed preparation. The chisel and sweep type tines are used for conventional tillage operations, weed control and seedbed preparation, respectively (Tullberg, 2000), whereas the narrow planter opener is used for planting and fertilizer placement (Aikins et al., 2017). It is also used in conjunction with spraying of pre-emergence herbicides for weed control. A 4WD John Deere 6520 tractor (engine: 78.2 kW, PTO: 70.8 kW, overall weight: 35.6 kN) was used for the study. Tractor tires were: 16.9R28 (single, front) operated at a pressure of 140 kPa and supporting a static load of 14.2 kN, and 18.4R26 (single, rear) operated at a pressure of 110 kPa and supporting a static load of 21.4 kN, respectively. The tractor was operated at a forward speed of 8 km h^{-1}.

Table 1. Bulk density and shear strength of the Black Vertisol at the experimental site in Felton, QLD, Australia.

Permanent traffic lane				
	Soil bulk density (g cm^{-3})		Shear strength (MPa)	
Depth (mm)	Mean	Standard deviation	Mean	Standard deviation
50	1.13	± 0.020	0.164	± 0.0149
100	1.208	± 0.002	0.187	± 0.0030
150	1.248	± 0.004	0.209	± 0.0120
Permanent crop bed				
	Soil bulk density (g cm^{-3})		Shear strength (MPa)	
Depth (mm)	Mean	Standard deviation	Mean	Standard deviation
50	0.881	± 0.039	0.027	± 0.0055
100	1.126	± 0.051	0.071	± 0.0101
150	1.227	± 0.002	0.092	± 0.0075

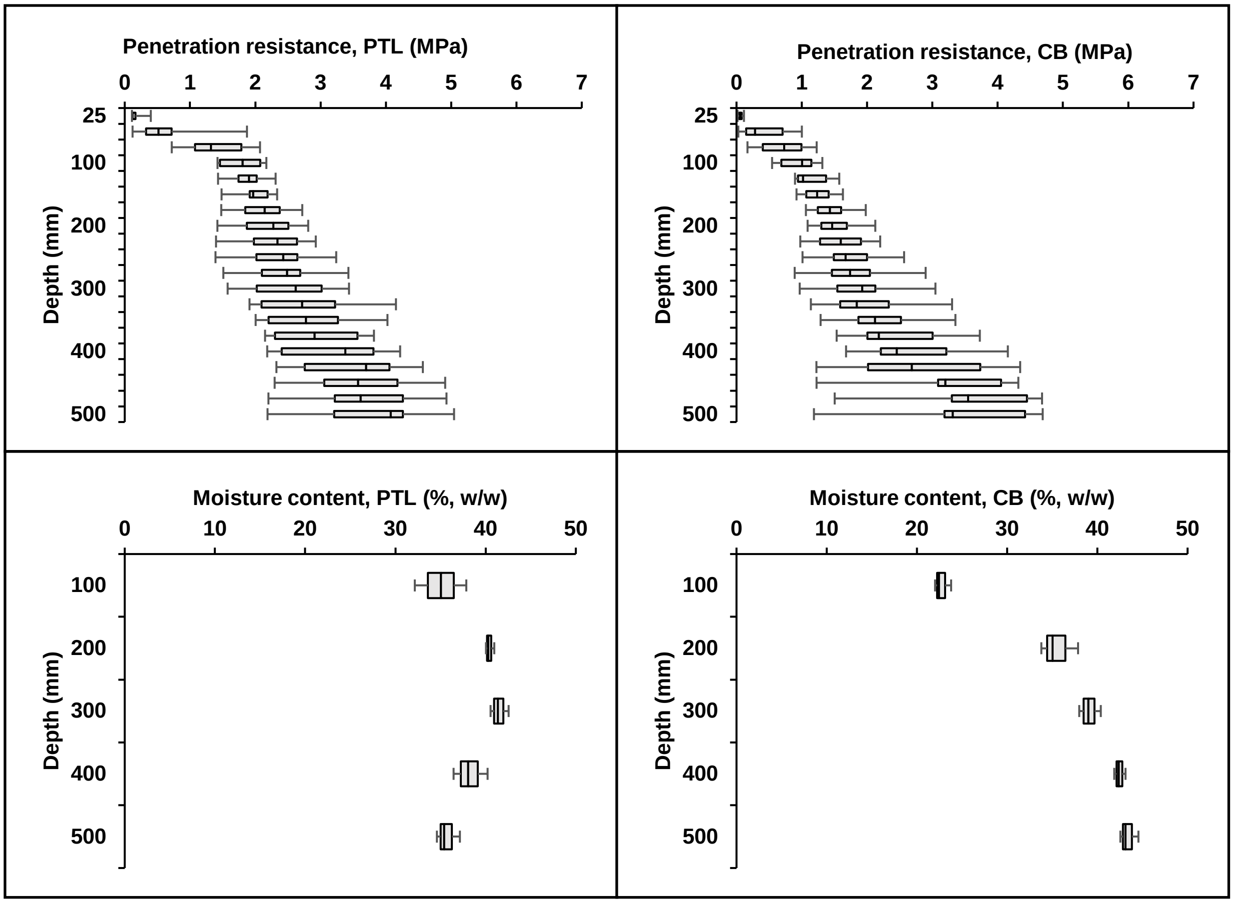

Figure 2. **Soil penetration resistance and moisture content recorded at the experimental site in Felton, QLD, Australia. PTL is permanent traffic lane, CB is permanent crop bed. Box plots show: Box plots show: Min, Q1, Med, Q3, and Max, respectively.**

Tillage Energy Unit

The unit used to measure draft forces is shown in Figure 3. Draft-sensing was achieved with chisel plough shanks attached to parallel link assemblies, movement of which was restricted by shear beam force transducers (SKT Model 1500). The force was monitored by a data logger (Rimik Data-Node) providing an oversampling and decimation system for filtering signal noise. The mean draught force for measurements at 2-*s* intervals was recorded for each transducer. All transducers were calibrated in the laboratory prior to the tests. The four parallel link assemblies were mounted on a 4-m wide three-point linkage toolbar fitted with adjustable depth control wheels at its extremities (Figure 3). Wheeled and non-wheeled soil conditions can be found immediately behind any tractor operation, therefore, this unit was able to monitor and compare the draft of soil engaging units (sweep tines, chisel tines, and narrow planter opener) operating in wheeled or non-wheeled soil. These tines were separately calibrated in the field. Transverse adjustment of tines allowed positioning in relation to wheel tracks, and all times were at precisely the same (adjustable) depth in relation to the toolbar.

Figure 3. Overview of the experimental tillage unit used in the study, (A): Close-up of data-logger, (B): Close-up of the force transducer, and (C): Plan view of tractor and tillage unit.

Statistical Analyses

Statistical analyses were undertaken with GenStat 16th Edition (VSN International, 2013). Analysis of variance (ANOVA) was performed using 1% and 5% probability levels, and least significant differences were used to compare means.

Results and Discussion

Draft Force

The relationship between draft and working depth for the three types of tines used in the study is shown in Figure 4. Draft force was significantly lower in non-wheeled compared with wheeled soil for all tines (P<0.01). The difference between draft in wheeled and non-wheeled soil found in this study was similar, but rather smaller than those reported in earlier work (e.g., Tullberg, 2000), and significantly affected by the type of tine. The variation of draft force between the different tines reflects the diversity of their purposes. The sweep tine, normally used for weed control and seedbed preparation, produced the greatest draft forces (3.03 kN) while the lowest draft force (0.89 kN) was found for the chisel tine, which is commonly used in tillage operations. In trafficked soil, the narrow planter opener showed the lowest draft force (1.92 kN) while it was highest (4.45 kN) with the sweep tine. It is also shown that even a single pass of a relatively small tractor (35.6 kN) can cause significant damage in terms of increased soil strength. Up to 80% of compaction damage may occur during the first pass (Spoor, 2006). In addition, the weight of tractors and combine harvesters has continued to increase (Kutzbach, 2000), and therefore traffic on moist, relatively weak soil can cause compaction to depths (e.g., >0.4 m), which may not be economically feasible to alleviate (Spoor et al., 2003). In any one crop cycle, up to 85%, 65% and 45% of the cultivated field area may be trafficked by at least one wheel pass during conventional, minimum tillage and no-tillage, respectively (Kroulik et al., 2009). Tillage repair treatments have not always produced satisfactory results, particularly when other subsoil constraints (e.g., sodic subsoil) are present (GRDC, 2009). This reinforces the need to minimize traffic impacts. A controlled traffic field consists of untrafficked, non-compacted crop beds, which are managed for efficient crop growth, and separated by compacted "roads" managed for efficient traffic. Hence, much could be gained from combining the benefits of no-tillage with controlled traffic farming practices. Data shown in Table 1 and Figure 2 also reflect the benefits of CTF in terms of improved soil physical and mechanical properties. This suggests that timeliness of operations and work rates within CTF systems may be significantly improved compared with non-CTF, because of reduced tillage energy requirements and rolling resistance. Higher compaction within permanent traffic lanes, improves trafficability and therefore tractive efficiency.

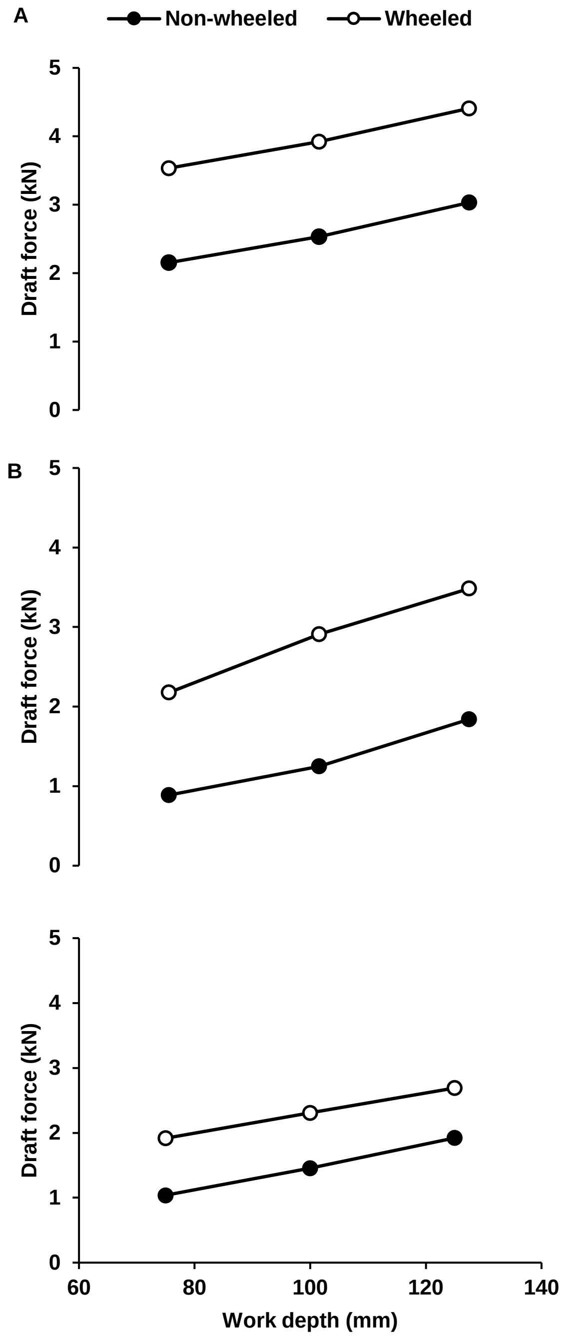

Figure 3. Tractor wheel traffic effects on draft forces at different depths as determined on a Black Vertisol, (A): sweep tine, (B): chisel tine, and (C): narrow planter opener, respectively.

Draft Saving

Results are presented as a ratio non-wheeled-to-wheeled draft in Figure 5. Considered in these terms, the greater draft reduction occurred with chisel tine and narrow planter opener (55% and 46%, respectively) compared with 39% for the sweep tines. This draft reduction was greater at shallower depth for all tines, suggesting that the compaction effect of wheel traffic is greatest in the surface soil. Chen and Yang (2015) found that the controlled traffic farming significantly reduced tine opener resistance by 30.3% and 21.6% at soil working depths of 50 mm and 100 mm, which is in good agreement with the results of the present study. Overall, it can be seen that avoiding till track wheel can save about 42% of energy.

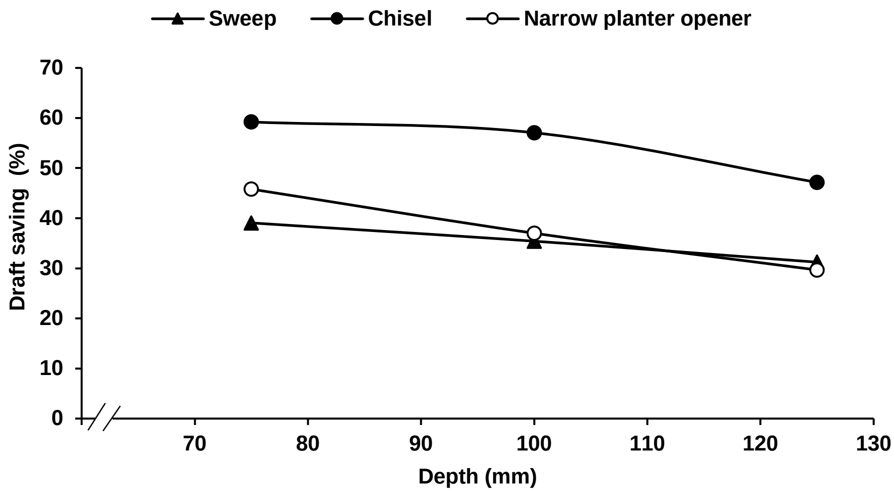

Figure 4. The effect of depth on draft savings for sweep and chisel tines, narrow planter openers in a Black Vertisol.

Compacted soil is more resistant to tillage forces and after tillage tends to be cloddier. Formation of large soil clods may require additional tillage, particularly for seedbed preparation. Figure 6 shows that large soil clods are formed behind previously wheeled soil. In no-tillage, the performance of narrow point tines varies significantly depending on their position relative to tractor wheels. Figure 7 shows the surface roughness observed after tillage of wheeled and non-wheeled soil. Uneven soil surface can affect seeding performance because of poor uniformity of distribution of seeds during the operation and poor soil-seed contact, which may affect germination rates (Chamen, 2015).

Figure 6. Large soil clods formed after tillage denotes detrimental effects of tractor wheel traffic on soil structure.

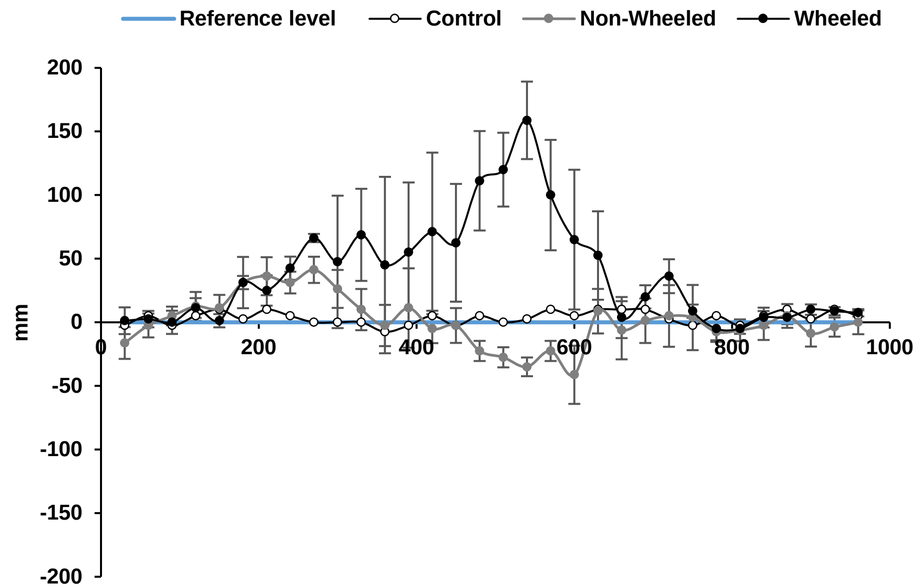

Figure 5. **Soil surface profile measurements.**

Conclusions

The main conclusions derived from this study are summarized below:

- The draft of narrow points, chisels and sweeps working in non-wheeled soil was approximately 40% less than the same points disturbing tractor wheel tracks.
- This draft reduction was relatively smaller at greater depths, and it was also less for sweeps tines compared with narrow points and chisel tines,
- Experimental work is being undertaken to estimate the effect of permanent traffic lane on rolling resistance, and to quantify the benefits of trafficking on permanent traffic lanes on timeliness of field operations.

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