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The effect of controlled traffic on soil physical properties and tillage requirements for vegetable production

J.E. McPhee [a,*], P.L. Aird [b], M.A. Hardie [c], S.R. Corkrey [c]

[a] Tasmanian Institute of Agriculture, University of Tasmania, P.O. Box 3523, Burnie, Tasmania 7320, Australia
[b] Serve-Ag Pty Ltd., P.O. Box 690, Devonport, Tasmania 7310, Australia
[c] Tasmanian Institute of Agriculture, University of Tasmania, Private Bag 54, Hobart, Tasmania 7000, Australia

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ABSTRACT

Demands for increased work rates and more timely operations in vegetable production have led to the use of more powerful and heavier machinery over the past 20 years. Increased vehicle weight, frequency of tillage, and capacity to work soil at sub-optimal moisture contents has increased soil compaction, and the tillage effort required for remediation. Despite conclusive evidence from other industries that controlled traffic systems improve soil conditions, reduce inputs, and overall improve productivity, such systems have not been widely adopted in vegetable production. Trials were established on red ferrosols in northern Tasmania to determine the effect of controlled traffic on soil compaction and penetration resistance, and the number of tillage operations required to prepare a seedbed for vegetable production. Potential mechanical, logistical or agronomic barriers to adoption of controlled traffic systems in vegetable production were also identified. Controlled traffic treatments demonstrated improvements in soil physical properties, and 20–60% fewer tillage operations, compared to conventional production systems. However, the measured benefits of controlled traffic were variable over the duration of the research studies due to limitations of current mechanisation. Adoption of controlled traffic in the vegetable production sector is currently limited by track gauge and working width incompatibility across the diverse range of equipment used, and machinery tracking issues associated with undulating topography.

1. Introduction

Controlled traffic farming (CTF) systems require all field machinery to have a common track gauge and working width, or multiple of it, allowing all wheels to be confined to defined traffic lanes (Baker et al., 2007). This permanently separates the crop zone and traffic lanes, which eliminates traffic-induced compaction from the crop growth zone (Chen et al., 2008; Li et al., 2007), allowing the two zones to be managed separately for the optimal performance of both. Traffic lanes are managed primarily to maintain surface drainage and trafficability, and while often left bare, may be planted in some cropping situations (Tullberg, 2010). The non-trafficked crop zone promotes development and maintenance of soil structure, which facilitates greater root development, maintenance of soil organic carbon, and improved infiltration and soil-water storage (Li et al., 2009).

CTF research has been conducted in many different environments, soils and cropping systems around the world (Bakker and Barker, 1998; Braunack and McGarry, 2006; Chen et al., 2008; Lamers et al., 1986; Tullberg et al., 2007; Vermeulen and Mosquera, 2009). In Australia, CTF research and development has been conducted in sub-tropical, rain-fed and irrigated grain and cotton systems on vertosols, dry land grain on deep sands, and in the sugar cane industry (Blackwell, 2007; Braunack and McGarry, 2006; Li et al., 2007, 2009; McHugh et al., 2009; Tullberg et al., 2007). Few studies have been conducted in irrigated vegetable production systems, on non-vertic soils, or in temperate cropping systems.

Numerous studies have demonstrated that controlled traffic improves soil physical conditions, including reduced bulk density and penetration resistance, and increased infiltration, hydraulic conductivity, and plant available water (Alvarez and Steinbach, 2009; Bai et al., 2009; Chamen and Longstaff, 1995; Li et al., 2007; McHugh et al., 2009; Tullberg, 2010; Unger, 1996). Braunack and McGarry et al. (2006) found significantly lower bulk density and penetration resistance to 30 cm depth in sugar cane controlled traffic trials in north Queensland, Australia. In China, Bai et al.

* Corresponding author at: Tasmanian Institute of Agriculture, P.O. Box 3523, Burnie, Tasmania 7320, Australia. Tel.: +61 3 6430 4910; fax: +61 3 6430 4959.
E-mail address: john.mcphee@utas.edu.au (J.E. McPhee).

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Nomenclature

GNSS	Global navigation satellite systems
RTK	Real time kinematic
CTF	Controlled traffic farming
SCTF	Seasonal controlled traffic farming
Track gauge	The centre to centre distance between tyres across a machine, perpendicular to the direction of travel

(2009) reported that after 10 years, bulk density in controlled traffic plots was significantly lower (5.2%) at 15–40 cm depth, compared to traditional tillage treatments. Data from a seven year trial in the semi-arid Loess Plateau of northern China also showed significantly lower bulk density at 10–20 cm depth under controlled traffic, compared to conventional tillage and traffic (Qingjie et al., 2009). McHugh et al. (2009) reported that, under zero-till grain production, bulk density at 10 cm depth reduced from 1.38 g/cm^3 to 1.28 g/cm^3 in as little as seven months after cessation of traffic on a vertosol. Reduction in bulk density was attributed to shrink-swell regeneration associated with seasonal changes in soil moisture. They estimated that at the rate of change observed under CTF, the average bulk density in the 0–30 cm layer of permanent beds could reduce from 1.4 g/cm^3 to near natural conditions (1.1–1.2 g/cm^3) after 36 months.

Few studies have reported the effect of CTF on soil water movement and availability. Tullberg et al. (2007) summarised 6 years of data from plots in southern Queensland, Australia, and 5 years of soil moisture data from Shanxi province, China. They measured infiltration of approximately 72% of annual rainfall in tilled wheeled soil, compared to 86% in non-tilled, non-wheeled areas in Australia, and 82–95% for similar treatments in China. Li et al. (2007) also reported rainfall infiltration in controlled traffic zero-tillage treatments was 12% greater than into wheeled, stubble mulched soil. On the Chinese Loess plateau, Bai et al. (2009) found the final infiltration rate of 159 mm/h in a zero-till, controlled traffic treatment was significantly higher than in the traditional tillage treatment (95 mm/h).

In a seven year trial on the semi-arid Loess Plateau of northern China, Qingjie et al. (2009) found that controlled traffic with full residue cover, compared to the conventional treatment of random traffic and full cultivation, had significantly higher soil water content to 150 cm depth at the time of sowing, resulting in 14.2% more water being stored in the soil during fallow periods. Differences in soil moisture between the treatments were attributed to changes in soil structure, tillage practices and residue management. Improved soil structure, as evidenced by lower bulk density and higher infiltration rate, also increased the capacity of the soil to store water. CTF also increased water use efficiency in most years, as increased yield was associated with higher soil water availability (Qingjie et al., 2009). Bai et al. (2009) reported higher volumetric soil moisture (20.5% increase in the 0–30 cm layer during fallow) in a controlled traffic, no-tillage treatment, compared to the traditional random traffic, full tillage treatment. Increased water storage was principally attributed to higher infiltration rates, enabling more rainfall to enter the soil profile.

Adoption of CTF has been shown to influence the timeliness of operations and/or the number of operations required for seedbed preparation (Chamen et al., 1992; Dickson and Ritchie, 1996; McPhee et al., 1995b; Spoor et al., 1988). Conventional vegetable production systems often rely on numerous tillage operations to alleviate harvest-induced soil compaction and prepare a seedbed for the next crop. Controlled traffic systems have been reported to improve timeliness through a combination of: (i) faster work rates due to reduced rolling resistance and improved traction (Taylor, 1983), and reduced tillage draft (McPhee et al., 1995a); (ii) earlier access to the field after rain or irrigation due to improved trafficability, (Dickson and Ritchie, 1996; McPhee et al., 1995b), and, (iii) reduced requirement for tillage (McPhee et al., 1995b; Tullberg et al., 2007).

In Tasmania, as elsewhere, opportunities exist for adoption of reduced or zero-tillage in vegetable production in conjunction with controlled traffic (Vedie et al., 2008), although current practices typically involve numerous passes of heavy machinery and intensive tillage to remediate the effects of harvest traffic. Traffic loads for crops such as potatoes, carrots and onions often exceed 300 t km ha^{-1}, while the seasonal tracked area is 3–5 ha ha^{-1}, with harvest operations contributing over half of the tracked area, resulting in close to 100% ground coverage over the crop cycle (McPhee, unpub. data). Similar loads and coverage intensity have been reported for vegetable production systems elsewhere in the world (Domzal et al., 1991; Kuipers and Zande, 1994).

In the red ferrosols, which are favored for vegetable production in Tasmania, Cotching et al. (2004) reported that current tillage and traffic practices led to reduced soil carbon and detrimental impacts on soil physical properties. Fields used for continuous cropping showed declines in soil organic carbon in the top 150 mm of 30%, and declines of microbial biomass carbon of 60%. Changes in soil physical properties, evidenced through increased topsoil cloddiness, were correlated with reduced crop yield. Although red ferrosols are considered to have excellent physical characteristics, and hence greater resilience to negative changes in soil condition compared to other soils exposed to similar intensive production practices, soil erosion, compaction and loss of organic matter are potential constraints to long-term productivity.

Comparatively little investigation has been made into the yield responses of vegetables to controlled traffic. Dickson et al. (1992) reported increases in total (14%) and marketable (18%) yield for potatoes grown under controlled traffic in Scotland, while Lamers et al. (1986) measured increases for ware (3%) and seed (7%) potatoes under controlled traffic in The Netherlands. Crops grown in a commercial seasonal CTF system in The Netherlands showed a variety of yield responses, ranging from no change to significant increases, such as 10% for onions and 35% for spinach (Vermeulen and Mosquera, 2009).

Adoption of controlled traffic in the Tasmanian vegetable industry is limited for a number of reasons, including the lack of compatible equipment across a diverse range of crops (McPhee and Aird, 2013), the influence of undulating topography (McPhee et al., 2013) and a lack of locally relevant experience. In addition, there is a lack of locally relevant research data to support adoption of CTF by the Tasmanian vegetable industry. This study was established to: (i) determine the effect of controlled traffic on soil physical properties in red ferrosols, specifically bulk density and penetration resistance (as indicators of soil compaction), (ii) evaluate the effect of adopting controlled traffic on the number of machinery operations for a range of economically important crops, and (iii) identify potential mechanical, logistical or agronomic barriers to adoption of controlled traffic systems within the Tasmanian vegetable sector. Seasonal CTF, in which all operations except harvest were confined to permanent traffic lanes, was initially used on one of the study sites due to the unavailability of compatible machinery for the harvest of the first crop. This situation reflects the broader challenges of controlled traffic adoption faced by the vegetable industry.