

Effects of Controlled Traffic on Infiltration under Simulate Rainfall

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ABSTRACT

Wheel traffic can lead to compaction and degradation of soil physical properties. This study, as part of a research on controlled traffic farming, assessed the impact of compaction from wheel traffic on filtration properties of the soil that had not been trafficked for five years. Soil compaction induced by different rear axle weight was conducted on a clay soil to simulate effects of traffic typical of grain production operations in the northern Australian grain belt. A portable rainfall simulator was used to determine infiltration characteristics. Crop performance was also monitored.

Time to ponding, steady infiltration rates and total infiltration were reduced significantly with axle load, although the soil surface was covered by 80 per cent crop residue. Poor crop establishment occurred on the wheeled plots, where plants were generally unhealthy compared with those under non-wheeled plots. Roots of plants on the wheeled plots were not able to penetrate the soil, while those from non-wheeled plots were longer and denser. Mean dry matter production of sweet corn decreased with axle loads, but none of these differences were significant.

These results demonstrated that soil compaction induced by wheel traffic has significant effects on infiltration properties and crop performance. The exclusion of wheel traffic under a controlled traffic farming system, combined with residue cover under conservation tillage practices, provides a way to enhance the sustainability of cropping this soil for improved infiltration, increased stored soil water and reduced runoff and environmental damage.

Keywords: Controlled traffic, soil compaction, infiltration, runoff, rainfall simulator, wheel traffic, conservation tillage, residue cover

1. INTRODUCTION

In dryland farming practices of grain production in northern Australia with highly variable,

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summer-dominant rainfall, crop yield depends on soil water stored during fallow (Freebairn et al., 1986). Therefore, increased runoff and reduced infiltration can limit crop yield. Low infiltration associated with high runoff can cause soil erosion, and this underlines the interest in best management practices to improve soil infiltration capacity and soil water storage for crop use, and to reduce damage to the environment.

The increase in the weight of farm machinery has increased the potential for progressive subsoil compaction during the last few decades (Rallison and Miller, 1982; Taylor, 1983; Hakansson et al., 1988). Most soil compaction occurs when soil is wheeled (compaction plus slippage) by tractors because soil management, weed control and planting operations usually occurred shortly after rainfall, when soil is moist and susceptible to structural deformation. Soils with a large clay content and water holding capacity are particularly susceptible to compression and shear under farm machinery (McGarry, 1993).

Extensive research has been carried out on the effects of heavy vehicles on soil physical properties and crop growth (Soane and van Ouwerkerk, 1994). High axle loads can cause soil compaction that may extend to 500 mm or greater. Lal et al. (1989) also found that axle load had a significant negative effect on crop yields. The process of soil compaction reduces total porosity and increases bulk density, resulting in changes in soil hydraulic properties (Horton et al., 1994). Shear deformation caused by wheel slip (i.e., relative movement between the tire and the underlying soil) can further damage the soil (Soane et al., 1980/1981), and reduce infiltration properties (Li et al., 2001).

Increased awareness of the problems associated with soil compaction has generated an interest in the benefits that could be obtained from controlled traffic farming systems (Tullberg, et al., 2001; Li, et al., 2005). However, little is known about soil compaction by different axle load on infiltration properties on a heavy clay soil compared with the non-wheeled soil under controlled traffic zero tillage system.

The objective of this study was to quantify the effects of soil compaction under different axle load on infiltration and runoff using a rainfall simulator. A portable rainfall simulator was used for this investigation, because it is an effective and appropriate tool for study on infiltration and soil loss (Silburn and Connolly, 1995; Littleboy et al., 1996; Loch, 1996). The areas used for wheeling and rainfall simulation in this study were the crop zones of the guard rows of five-year controlled traffic zero tillage experiment.

2. MATERIALS AND METHODS

2.1 A Rainfall Simulator

A portable rainfall simulator based on the design of Bubenzer and Meyer (1965) was available to apply simulated rainfall to measure runoff. Three oscillating Veejet 80100 nozzles were placed evenly on the top bar, and water was pumped to the nozzles (Fig.1) with a supply pressure maintained at 60 kPa to produce drop size and energy similar to natural rain (Loch, 1996). Water was supplied from a tank on a truck, which needed to be refilled after two simulation runs. Total runoff and runoff rates were monitored using a tipping bucket

methodology and computer program in one-minute time steps (Ciesiolka et al., 1995). Runoff via this tipping bucket system was collected into a large container for each simulation plot as a gross check. The rainfall simulator covered two subplots (0.75 m by 2 m each) in each rainfall simulation run.



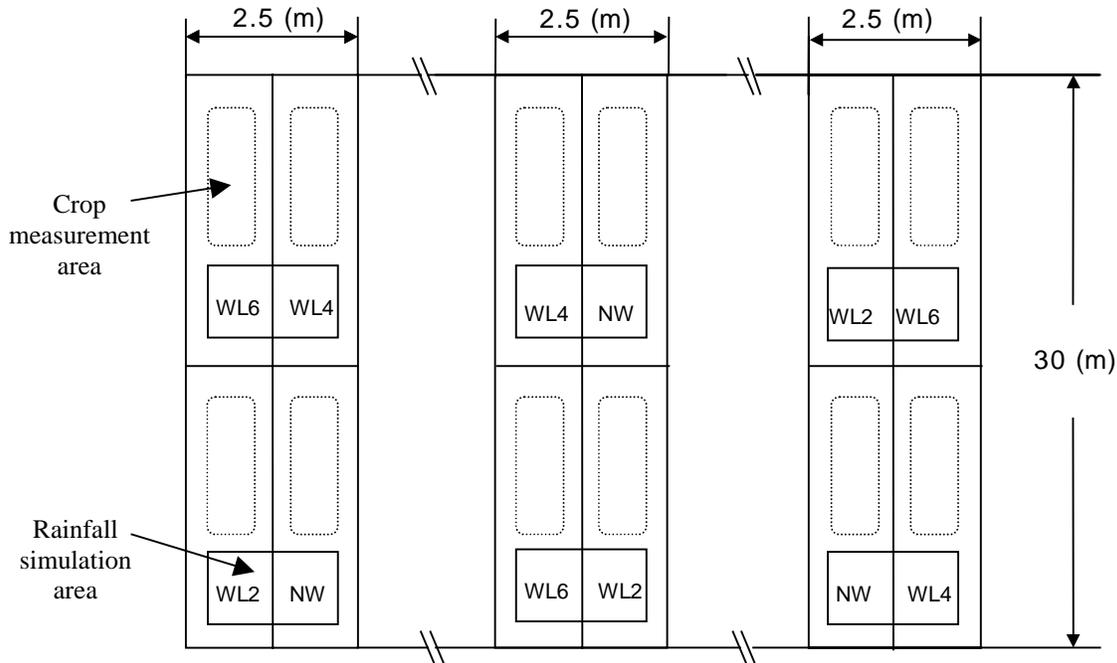
Fig.1 A portable rainfall simulator with two tipping buckets connected to a laptop computer.

2.2 Site Description

The experiment site was at the University of Queensland, Gatton (27°30'S, 152°27'E), northern Australia, with mean slope of 6-8 per cent, on a self-mulching black earth. The soil plastic limit gravimetric water content was 27 per cent (G. Sharp, pers. comm.). Average annual rainfall is 785 mm with 70 per cent of the total falling in October-March. A controlled traffic experiment, providing a 2.5-m-wide by 30-m-long cropped 'seedbed' and 0.5-m permanent traffic 'lanes', was set up in 1994 to investigate the effect of controlled traffic on runoff and crop production. The experiment was designed to use the guard rows for wheeling and rainfall simulation. These guard rows had been used for controlled traffic zero tillage over 5 years, and provided a desirable non-wheeled condition.

2.3 Experimental Layout

Three guard rows, the crop zones have been under controlled traffic zero tillage over five years were used for the wheeling and simulation experiment. Each guard row was split into four treatments, representing four rear axle loads, randomly arranged (Fig.2). The four treatments were:



NW-non-wheeled or zero rear axle load under controlled traffic system
 WL2 -- wheeled with 20 kN rear axle load
 WL4 -- wheeled with 40 kN rear axle load
 WL6 -- wheeled with 60 kN rear axle load

Fig.2. Experiment layout of wheeling and rainfall simulation experiment.

Wheeling with different axle loads

The three crop zones under controlled traffic zero tillage over five years were in fallow after winter wheat harvest in October 1998 until a single wheeling was imposed lengthwise taking 3-5 passes side by side to cover the whole wheeled area in each section. A 2WD tractor (John Deere 1040) with 20 kN rear axle load and a 2WD tractor (John Deere 4040) with 40 kN rear axle load were used for the treatments of WL2 and WL4, respectively.

The rear tire width of the two tractors was 0.23 and 0.46 m, respectively. The tractor with 60 kN rear axle load was obtained by adding extra weight to the rear of the 4040 tractor for treatment WL6. Rolling resistance-motion resistance or towed force-was measured by towing the tractor on soil in similar condition near the site. Wheel slip was only that of self-propulsion (2-3 per cent). The tire pressure of the tractor rear wheels was approximately 150 kPa and working speed approximately 3-4 km/h throughout the wheeling treatments. Soil volumetric moisture content prior to wheeling was 21.8 per cent at 100 mm depth, which was less than the plastic limit (27 per cent for the site).

The soil surface of the wheel-track area was lightly hand-raked after wheeling to remove any surface roughness effects on infiltration. In the non-wheeled area, any soil surface crust was lightly disturbed to ensure that any previous surface seal did not affect infiltration. Soil surface cover of 8 per cent for each rainfall simulation was added as wheat straw, after wheeling to

simulate residue cover condition under zero tillage practice. There are various methods used for measuring residue cover (Morrison et al., 1993), but in this study, residue cover was estimated using the method of photo standards for winter cereals (Molloy and Moran, 1991).

Rainfall simulation

The rainfall simulator was calibrated prior to the experiment, and rainfall simulation was conducted within one week of wheeling. Rainfall was applied at a constant rate of 82 mm/h for about 80-90 min to simulate a moderate rainfall event, with rainfall equivalent to a five-year return period 40-min design rainfall event at Gatton (Pierrehumbert, 1977). Greater rainfall intensity would have facilitated easier to this experiment by prediction runoff more rapidly, particularly on non-wheeled residue protected plots. Sweet corn was planted after rainfall simulation, and crop samples were only taken in the crop measurement areas in order to achieve accurate results.

2.4 Measurements

Time to ponding, total rainfall and runoff and rainfall and runoff rates were recorded using the tipping bucket methodology of Ciesiolka et al. (1995). Infiltration rates and total infiltration were calculated by subtracting runoff rate and total runoff from rainfall rate and total rainfall at any time, neglecting surface retention (Silburn and Connolly, 1995).

Crop samples above ground were taken at maturity in the whole crop management area (Fig.2) and were oven-dried at 50 °C for about 48 hours.

Data were analyzed by the general linear model (GLM) procedure of SAS version 6.12.

3. RESULTS

3.1 Infiltration Properties

Time to ponding, steady infiltration rate and total infiltration were all significantly greater ($P < 0.05$) for non-wheeled soil under controlled traffic system compared with all the wheeled soils (Fig.3). In most cases, infiltration capacity significantly decreased with axle loads, and the least infiltration occurred in the treatment wheeled with 60 KN rear axle load (WL6). The greatest infiltration occurred in non-wheeled soil, in which time to ponding, steady infiltration and total infiltration were about 2, 1.5 and 1.3 times as much as soil wheeled with 60 KN axle load, respectively. Approximately 90 per cent of total rainfall (110 mm) infiltrated into non-wheeled soil during the simulation period, but this reduced to 70 per cent for the 60 KN axle load treatment.

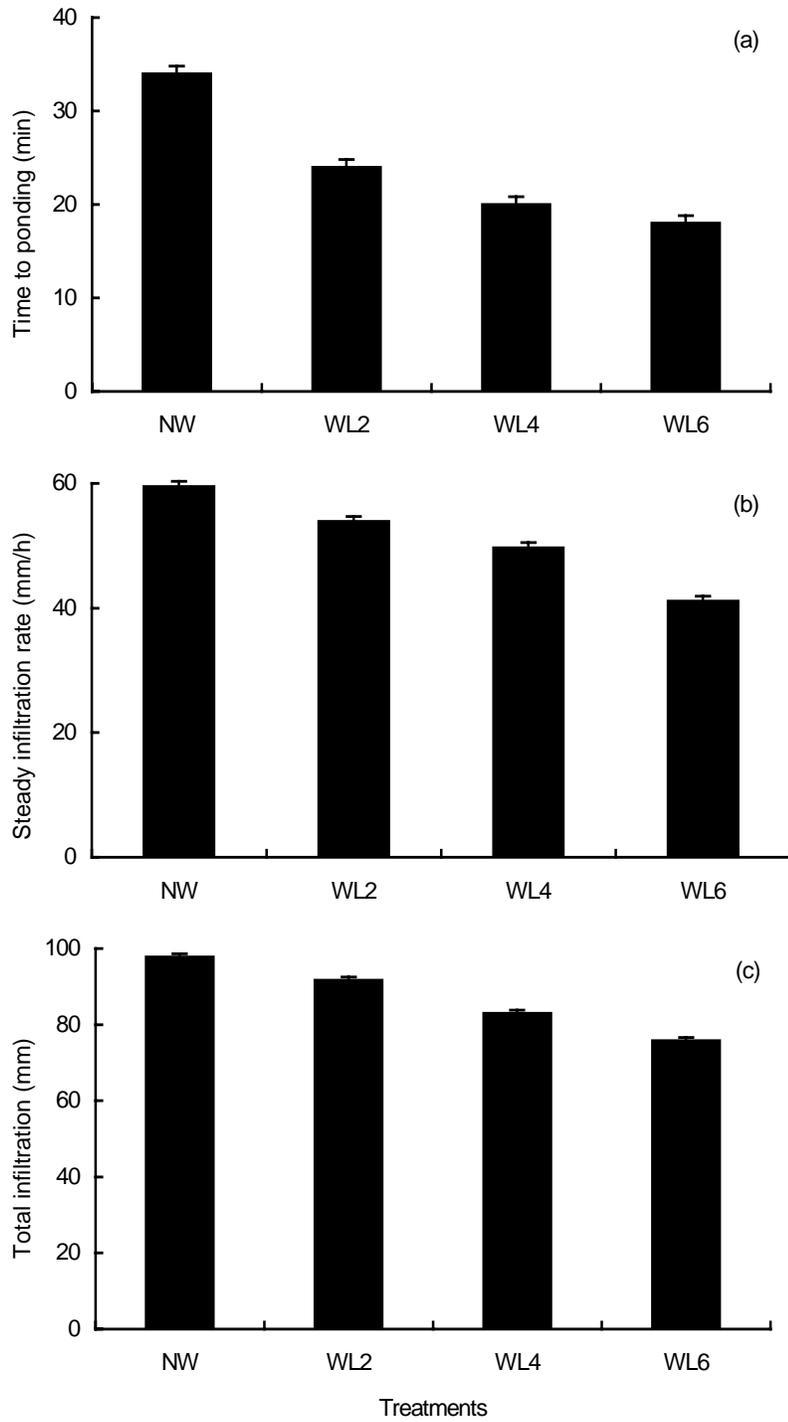


Fig.3 Axle load effects on (a) time to ponding, (b) steady infiltration rate and (c) cumulative infiltration under simulated rainfall (110 mm). Vertical bars indicate standard errors of means (n=3, P=0.05)

3.2 Crop Response

Poor crop establishment occurred on the wheeled plots (Fig.4), where plants were generally unhealthy and weak (left side) compared with those under non-wheeled plots (right side).



Fig.4 Example of the comparison of crop establishment between non-wheeled (right) and wheeled (left) soils.

Roots of plants from non-wheeled plots (right side) were also longer and denser than those from wheeled plots (left side) (Fig.5), which were not able to penetrate the soil and went sideways instead.



Fig.5 Example of the comparison of roots development between non-wheeled (right) and wheeled (left) soils.

Mean dry matter production of sweet corn decreased with axle loads, but none of these differences were significant (Fig.6). The greatest yield was obtained from non-wheeled treatment and the least from treatment wheeled with 60 kN axle load. Mean yield increase for the non-wheeled treatment varied between 29 and 63 per cent.

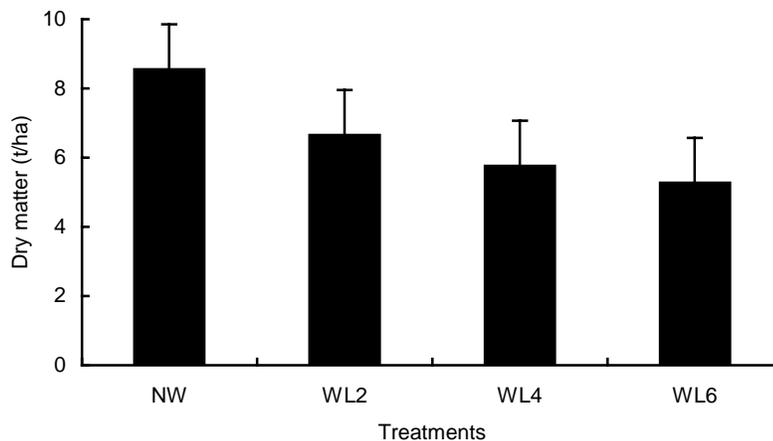


Fig.6. Effect of axle loads on total dry matter of sweet corn. Vertical bars indicate standard errors of means.

(n=3, $P < 0.05$)

4. DISCUSSION

This study has clearly demonstrated that wheel traffic has a great negative impact on infiltration capacity compared with non-wheeled treatment under controlled traffic system under simulated rainfall, although the soil was covered by 80 per cent crop residue. This result is similar to that from the five-year field experiment under natural rainfall (Tullberg et al., 2001; Li et al., 2005) and confirms the observation by Potter et al. (1995), that traffic greatly reduced the infiltration rate of vertosols.

In this study, infiltration for non-wheeled treatment with residue cover under controlled traffic zero tillage appears to be similar to that of virgin soils (Connolly et al., 1997), but one wheel pass reduces to that of long-term cultivated soil (Freebairn et al., 1984; Silburn and Connolly, 1995). The implication of these results is that wheeling is responsible for a pervasive sub-surface layer of degraded soil, which might be a major problem for zero tillage as suggested by Tullberg et al. (2001) who also demonstrated that normal tillage at 125 mm depth did not undo this wheeling effect.

The wheeling treatment here was intended to simulate the tillage/planting operations of broad acre grain production, so the tractors used were common 2WD units with rear axle weights of 20, 40 and 60 kN. It might be argued that the pressure used in the rear tires was at the upper end of the normal ranges (80-160 kPa), and that the application of wheeling to the complete plot area does not exactly simulate farm practice.

Tire pressure is generally acknowledged to have a smaller effect on the subsoil than surface soil (Hadas, 1994). Since infiltration behavior of residue-protected soil appears to be largely a function of the sub-surface layer in compacted areas, where ameliorative change occurs relatively slowly, the complete wheeling treatment is likely to be similar in its outcome to that of the random wheeling effects which occur over time during cropping. Kuipers and van-de Zande (1994), for instance, demonstrated that tractor wheels traffic an area of 0.5-1.5 times the crop area in each crop production cycle, again suggesting that a wheeling of the complete plot area (as used in this study) is not excessive compared to common practices.

Soil moisture at the time of wheeling appears to have a great effect on infiltration and runoff. For example, the soil moisture content at the time of wheeling was 21.8 per cent, resulting in steady infiltration rate of 49.7 mm/h for wheeled treatment with axle load of 40 kN. This number was higher than that of 23.7 mm/h for the similar treatment and the same axle load but soil moisture content was 28.0 per cent at the time of wheeling (Li, et al., 2001). For a given axle load, the wetter the soil and smaller its strength, the greater the damage as pointed out by Kirby and Kirchof (1990). Infiltration capacity was influenced by axle load, wheel slip and soil moisture content at the time of wheeling, and this was associated with the tractor energy dissipated in the soil (Li, et al., 2001).

Wheeling has negative impact on crop establishment, root development and crop performance according to Boone (1988). In this experiment the non-wheeled treatment produced the greatest dry matter of sweet corn, but these differences were not significant. Results from the five-year field experiment described by Li, et al. (2005) indicated that summer crops had less response than winter crops to wheel traffic and tillage management and in this area soil

disturbance during rainfall simulation might also offset the benefit from non-wheeled plots.

5. SUMMARY

The effects of wheel traffic on infiltration on a vertosol in a controlled traffic system for over five years were investigated under simulated rain, indicated that:

- (1) Wheel traffic has a large and significant negative effect on infiltration properties, compared with non-wheeled treatment under controlled traffic system.
- (2) The effects of wheel traffic on infiltration, crop performance and root development increased with axle load when wheeling is applied.
- (3) Infiltration will be improved and runoff will be reduced when wheel traffic is removed from a controlled traffic system, and soil is covered by crop residue.
- (4) The data suggests that infiltration is controlled by a degraded sub-surface layer when the soil is wheeled and also covered by crop residue.

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