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Impact of cotton picker traffic on vertosol soil and yield in individual rows

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Abstract. This study investigated the impact of soil compaction owing to cotton picker traffic, and the impact of this compaction on cotton yield on a row-by-row basis across the field under both random traffic farming (RTF) and controlled traffic farming (CTF) systems. Measurements of soil water content, dry bulk density and soil penetration resistance were taken and compared with a depth of 80 cm both before and after traffic. It was found that the traffic of JD7760 round-bale cotton picker caused significant compaction in cotton rows and furrows located between, adjacent to, and in wheel tracks under both RTF and CTF systems, particularly for the top 30-cm depth. Because of the soil compaction, the yield was more significantly reduced (7~10% by the machine-pick method) in the rows between the dual-wheel than in those adjacent to the wheel track. Adopting CTF reduces the area of soil compaction and ensures the maintenance of soil characteristics of the cultivated portions of the farm, hence enhancing cotton yield.

Keywords: cotton picker, soil compaction, controlled traffic farming, yield.

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Introduction

Cotton (*Gossypium hirsutum L.*) is an important industrial crop of considerable economic value in many countries. The major cotton producers in the world include China, the USA, India, Pakistan and Brazil. They together contribute ~75% of global production (Yadav *et al.* 2018). In recent years, Australia has become one of the leading cotton producers and the third-largest exporter, with the highest average yield per hectare in the world (Eskandari *et al.* 2017, 2018).

Cotton performs well on Vertosols, earning the worldwide title 'Black Cotton Soil' (Ahmad 1983; Oza and Gundaliya 2013). This reputation is due to cotton's vertical root system, which is not significantly damaged by the cracking of the Vertosols (IUSS Working Group WRB 2015). Vertosols make up ~75% of the soils under cotton production in Australia (McKenzie *et al.* 2003). These soils have a unique morphology resulting from the swelling–shrinking of the clays on changes in moisture content (Potter and Chichester 1993; Patil *et al.* 2012). However, Vertosols are susceptible to compaction, especially under wet conditions (Chan *et al.* 2006). With just one pass of heavy machinery, significant compaction reaching deep into subsurface layers can occur (Bennett *et al.* 2019).

Soil compaction is also a major global challenge in mechanised crop production (Soane and Van Ouwerkerk 1994; Batey 2009; McPhee *et al.* 2018). This challenge is exacerbated when the machinery size and weight continue to increase in the quest to increase production and profitability (Hamza and Anderson 2005; Głab 2014). It has been suggested that one of the effective ways to prevent or minimise soil compaction in a highly mechanised farming system is the adoption of CTF that minimises the area affected by machinery traffic (Tullberg 2010).

The farming systems, in terms of machinery traffic, employed by cotton growers around the world can broadly be classified as either random traffic farming (RTF) or controlled traffic farming (CTF). RTF is the conventional system of traffic in which there are no permanent paths for machinery traffic (Gasso *et al.* 2013). This implies that over time, soil compaction owing to machinery traffic occurs haphazardly on the cultivated field. Trafficking under RTF typically covers 85% and above of the field whenever a crop is produced (Kroulík *et al.* 2009). This is compared with CTF where dedicated permanent lanes are used year-in and year-out, restricting machinery passage to specific uncultivated paths (Tullberg *et al.* 2007; Antille *et al.* 2016; Lu *et al.* 2016).

Around the world, farmers employ a variety of harvesters and pickers to harvest cotton. Australia and the USA are the two main countries in the world where all cotton harvesting is mechanised (Muthamilselvan *et al.* 2007). One of the most popular cotton pickers in these two countries is the John Deere

7760 cotton picker (JD7760). As present, this cotton picker is used in more than 80% of Australian cotton farms (Bennett *et al.* 2019). Its high adoption rate could be attributed to its improved operation safety, efficiency and operating costs relative to previous basket pickers (Bennett *et al.* 2015). Particularly, the new round-bale cotton picker has eliminated the need for module builders, boll buggies and tractors, and, thus, has significantly reduced the labour cost (Jason Daniel 2008).

However, with all these improvements, this cotton picker weighs ~32 t. This is about two times as heavy as its previous models (Braunack and Johnston 2014; Bennett *et al.* 2015), which leads to increased compaction in the wheel tracks, especially in the topsoil (Bartimote *et al.* 2017), and can spread to adjacent rows (Braunack and Johnston 2014). In an attempt to minimise compaction risk as a result of an increased axle weight, the front axle has been fitted with dual-wheels and larger tyres (520/85R42 R1R2; John Deere 2016). Nevertheless, traffic of the inner and outer front dual-wheels has been identified as a major cause of compaction to depths of up to 80 cm in Vertosols (Bennett *et al.* 2017).

A modified version of the JD7760 picker has also been adapted for harvesting under CTF (CTF7760). The modifications include an increase in the frontage width from 6 to 9 m and the replacement of the front dual-wheels with single 620/70R42 wheels (Antille *et al.* 2016). Bennett *et al.* (2017) reported that the main difference between the use of the JD7760 and CTF7760 is that ~66% and 50% of cotton furrows are subjected to harvester wheel traffic under RTF and CTF respectively. However, harvest traffic from the JD7760 picker, regardless of RTF or CTF, still results in soil degradation in the wheel track at different soil depths (Bennett *et al.* 2016).

Harvester traffic is a serious issue, particularly when soils are subjected to trafficking without annual ripping operations (Hamza and Anderson 2005). Given that Vertosols readily experience significant compaction even as a result of a single pass, trafficking with the heavier JD7760 and CTF7760 worsens the compaction (Bennett *et al.* 2017). Daniells (1989) reported that the yield of cotton grown in Vertosol could be reduced by more than 33% when the soil is subjected to harvest traffic, particularly under wet conditions. Coelho *et al.* (2000) also observed a significant decline in cotton yield as a result of compaction when dry bulk density increased to 1.60–1.70 g/cm^3. Also, compaction resulting from the random traffic of a harvester was found to be the main reason for the significant decrease (24%) in cotton yield reported by Braunack (2013).

A substantial amount of research (Braunack 2013; Braunack and Johnston 2014; Antille *et al.* 2016; Bartimote *et al.* 2017; Bennett *et al.* 2017, 2019; Roberton and Bennett 2017) has studied the effect of compaction due to JD7760 traffic on soil structure and cotton yield. However, these results are usually represented as the overall results across the field. There appears to be a lack of data and studies in the row-by-row impact of the JD7760 cotton picker traffic on soil compaction and cotton yield.

Because of the wheel arrangement of the JD7760 and CTF7760 cotton pickers relative to cotton rows, the degree of compaction caused by wheel traffic will not be uniform for all rows. Braunack and Johnston (2014) found that compaction caused by harvester wheel traffic could spread to adjacent rows. To understand the variation in cotton yield across the field and within a picker pass, investigation of row-by-row variations in compaction, particularly in Vertisols, was necessary.

Therefore, this study aimed to investigate soil compaction owing to the JD7760 cotton picker and its influence on individual cotton rows under RTF and CTF systems. Understanding the row-by-row variation will enable cotton farmers to be more specific in their compaction remediation treatments, so as to achieve both cost and time savings by adopting better strategic management and the development of aids for better production decision-making under different levels of soil compaction.

Materials and methods

Site description

Two cotton fields were measured to investigate the impact of JD7760 cotton picker traffic on soil compaction and potential yield row-by-row in the 2016/2017. Both sites (Undabri and Yambacully) were located near Goondiwindi, Queensland, Australia (Table 1). These fields were chosen because of their range of traffic histories that could be assessed. The fields were also selected to be representative of Vertosols as much as reasonably possible. The Grey Vertosol is the predominant soil type in these districts; however, because these are alluvial soils, soil sequences are common. No deep-soil tillage occurred before planting at both sites. Cotton (*Gossypium hirsutum* L. S71BR) was planted in this region because of the suitability of the soils, access to water, and a suitable climate. The industry-standard farming system is random traffic farming (1.0-m row spacing), which has been in operation at Undabri since 2012 and is harvested by the JD7760 standard configuration, while CTF with 1.5-m row spacing was adopted at Yambacully in 2015 and the harvest was picked with the CTF7760 modified harvester.

Experiment design

The experiments were conducted to examine the influence of soil compaction at the level of individual rows and furrows. Two blocks were chosen in each site. Each block had six

Table 1. Sites discerption, soil type, irrigation and harvest system

Site	Region	Soil	Location	Row spacing (m)	Irrigation system	Equipment
Undabri	Goondiwindi, Qld	Grey Vertosol	28°23′26.78″S, 150° 9′40.54″E	1.0	Centre pivot system	JD7760 standard
Yambacully	Goondiwindi, Qld	Grey Vertosol	28°27′2.40″S, 150° 9′35.27″E	1.5	Furrow system (siphon method)	CTF JD7760 modified

sampling transects. The transects were randomly assigned in each block to reduce the chance of biased results. The blocks were designed so that they captured the full frontage of the JD7760 (six picking rows). The length of each block was 324 m, and the width was 6 m for RTF and 9 m for CTF (Fig. 1). The transect dimensions were 1.5 m in length and 6 m in width to correspond with the JD7760 standard frontage, whereas the width was 9 m to match the CTF traffic system (Fig. 1). Both harvesters had the same front and rear wheel loads (10 860 kg at front and 8250 kg at rear when the harvesters were empty), but they had different wheel configurations (dual-wheel and single-wheel) to match random and controlled traffic systems. Soil water content (Swc), dry bulk density (Pb) and soil penetration resistance (SPR) were measured before and after harvester traffic to a depth of 80 cm, to assess the degree of soil compaction. These parameters were measured in cotton rows numbered Row 1, Row 2 and Row 3. At the RTF site, Row 2 was located between the front dual-wheels of the JD7760, and Row 1 and Row 3 were located on the outer and inner sides of the wheels respectively (Fig. 2a). At the CTF site, CTF7760 wheel traffic was between Row 2 and Row 3. Row 1 was separated from the wheel by Row 2 and a furrow because of harvester modification (Fig. 2b).

Soil sampling

A portable petrol post driver (Christie's Engineering CHPD 78 Post Driver, 4 strokes), volumetric cylinder (thin-walled metal tube 1500 mm in length and 52.5 mm in diameter), and foot lever were used to collect soil samples for both sites. Samples

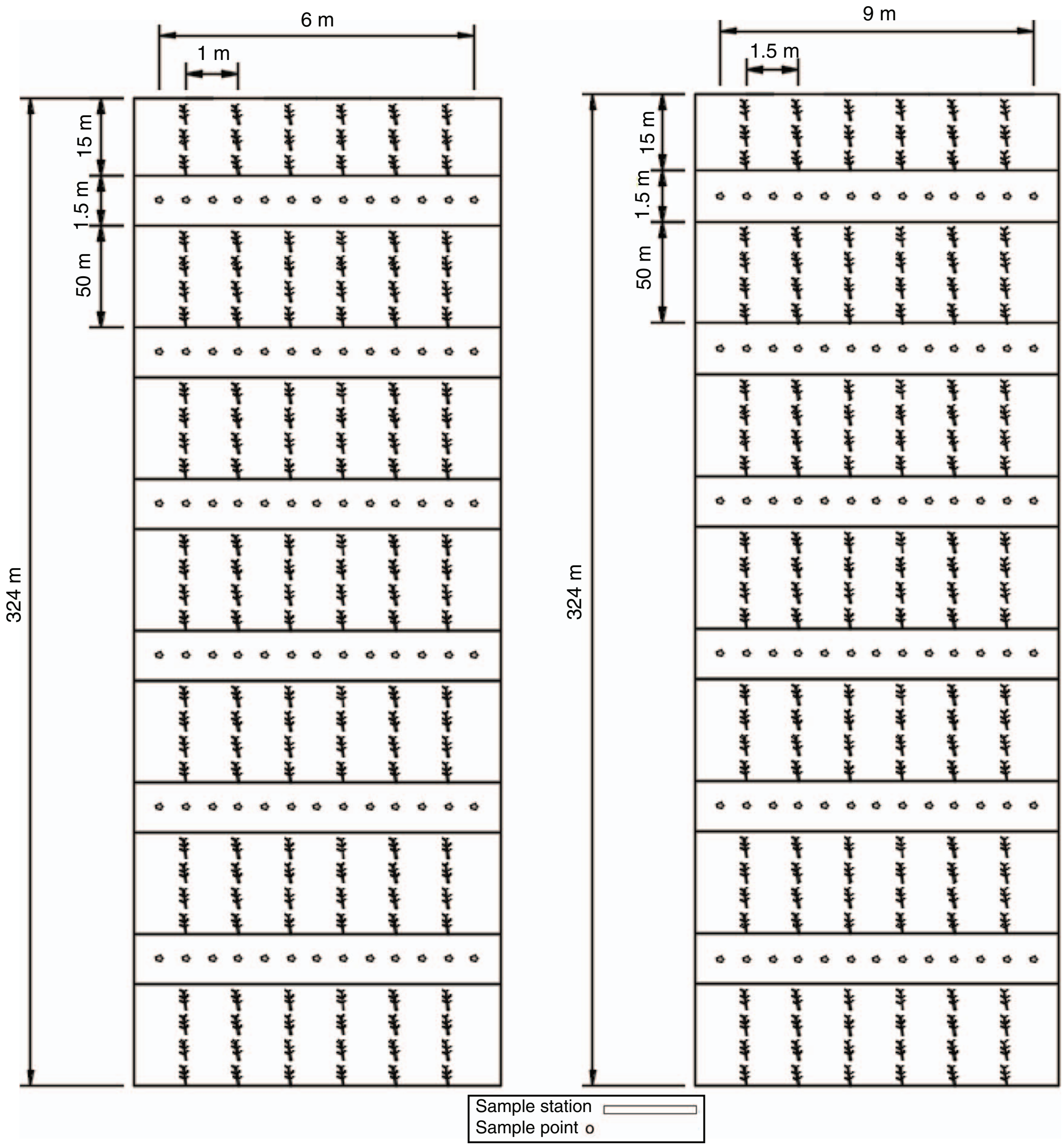

Fig. 1. Experimental design shows positioning of soil cores. Undabri site (1.0-m row spacing, left) and Yambacully site (1.5-m row spacing, right)

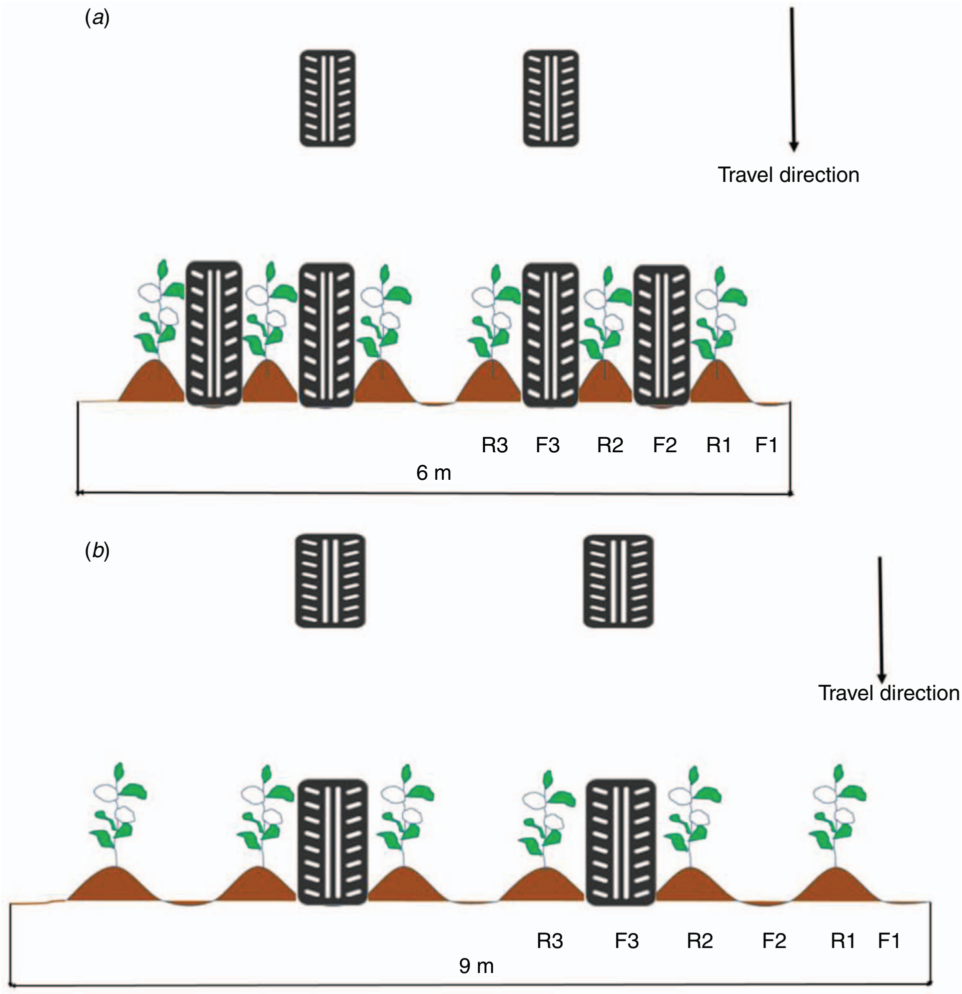

Fig. 2. The wheel track of the JD7760. (*a*) Standard configuration under 1.0-m row spacing (RTF), and (*b*) the controlled traffic-configured CTF7760 (1.5 m row spacing). The letters R1, R2 and R3 represent Row 1, Row 2 and Row 3, and F1, F2, and F3 represent Furrow 1, Furrow 2 and Furrow 3 respectively.

Table 2. Summary details of soil sampling in the study period

Trial period	Field	Details
May 2017	Undabri	1 field, 2 paddocks per field, 6 transects in each paddock.13 sample points in each transect (including rows and traffic furrows and centre differential position), 8 soil depths within 1 sample point; sampling occurred before and after traffic; total of 2496 samples.
May 2017	Yambacully	1 field, 2 paddocks per field, 6 transects in each paddock.13 sample points in each transect (including rows and traffic furrows and centre differential position), 8 soil depths within 1 sample point; sampling occurred before and after traffic; total of 2496 samples.

were collected from the position of each cotton row and furrow of each transect to a soil depth of 80 cm before and after harvester traffic. The incidence of sampling was based on the procedure outlined in McKenzie *et al*. (2002). Soil sample collection was performed by driving the sampling cylinder vertically into the soil to the desired depth, by using the jackhammer. The cylinder was carefully removed by the extraction lever. Because the core-sampling procedure used a hammering action to push the cylinder to the desired depth, the extracted core length was measured and compared against the hole depth to ensure that compaction had not occurred during sampling. It was found that this approach did not cause compaction of samples (McKenzie *et al.* 2002; Bennett *et al.* 2017). Each tube provided an 800-mm sample and could be separated into 100-mm subsamples. Overall, the field trials provided a total of 624 tubes, which, divided into 10-cm subsamples, generated a total of 4992 samples (Table 2).

Soil water content and dry bulk-density measurements

The laboratory measurements were based on the method outlined in International Organisation for Standardisation (11272, ISO 2017). Soil cores were directly weighed after completing field experiments, and then placed in the oven for at least 72 h at 105°C, so as to determine the dry weight of each sample. Soil water content (Swc) was calculated on the basis of gravimetric, and then converted into volumetric, soil water content and is shown as a percentage. The dry bulk density (Pb) of the soil was calculated by oven-dry weight of soil per unit of volume, reported in g cm^{-3}.

Soil penetration resistance

A static cone penetrometer CP40II (Rimik) and load cell rated at 100 kg were used to measure soil penetration resistance. A small cone size (130 mm^2, 12.83-mm diameter) with shaft (9.53-mm diameter) was selected because it suits hard soils (ASAE 1986). This cone penetrometer was able to measure soil strength up to 5.6 MPa and can reach soil depth of 750 mm, with intervals of 10, 15, 20 and 25 mm (Rimik 2017). The penetrometer was mounted to the constant drive device to ensure that the cone was driven into the soil at a constant penetration rate (42.5 mm/s; Rimik 2017). The crop and cotton hills were removed from soil sampling stations. In both farms, SPR measurements were taken when the soil cores were collected (Ayers and Perumpral 1982). Resistance measurement was recorded at each 10-mm depth (up to 700 mm), with an insertion spacing of 250 mm across picker frontage (Braunack and Johnston 2014). These processes resulted in 660 insertions for both Undabri and Yambacully.

Cotton yield

The cotton crops were planted with row spacing of 1.0 m at Undabri and 1.5 m at Yambacully. Two cotton pickers (JD7760) were employed to harvest the study areas. A standard picker (6-m frontage with front dual-wheels) was used (Fig. 3*a*) to harvest at Undabri. The CTF7760 modified harvester was employed (Fig. 3*b*) at Yambacully, enabling it to pick 6 rows (1.5-m row spacing) over 9 m. This modification also involved removing the dual-wheels and replacing them with a single tyre 620/70R42. The 7760 John Deere Harvest Identification (Harvest Doc and CAN-BUS) and John Deere-Datalogger were also utilised in this study to extract yield data from individual rows. Six flow-mass sensors were installed on the ducts of the harvester to measure the amount of yield passing through the ducts during harvest operation (Fig. 4). The John Deere-Datalogger transferred the data so that it was available in the MyJohnDeere portal and was processed and set up as an excel spreadsheet. The hand-picked yield was also used to calibrate the machine-picked yield, because the sensors of machine-picked yield might have some calibration limitations. Furthermore, the measurement of yield of each row was accounted as a 1.5 m^2 per metre for CTF and a 1.0 m^2 per metre for RTF, which were, thereafter, converted into bale per hectare (1 bale = 227 kg lint yield).

Statistical analysis

ANOVA was performed in this study. The data were analysed statistically by utilising the software package (Statistical Package for Social Scientists) IBM SPSS version 23.0 (IBM 2016). Significant difference between data were tested using the l.s.d. test.

Results

For the soil characteristic results presented in the figures of this section below, the symbol (*) represents a significant difference at $P = 0.05$ level between before and after harvester traffic. The letters R1, R2 and R3 in the figures represent Row 1, Row 2 and Row 3 respectively, and F1, F2 and F3 represent Furrow 1, Furrow 2 and Furrow 3 respectively.

Soil water content and dry density

Figure 5 shows the results of Swc before and after harvester traffic in Row 1 for Undabri. When comparing before and after traffic, there was not a significant difference in Swc at $P = 0.05$ level for all cotton rows and furrows of both sites throughout the profile depth. This was because the soil-sample collection occurred immediately before and after traffic and within a 1–2 day duration.

Fig. 3. The John Deere 7760 cotton picker. (*a*) The standard John Deere 7760 cotton picker. (*b*) The modified John Deere 7760 cotton picker.

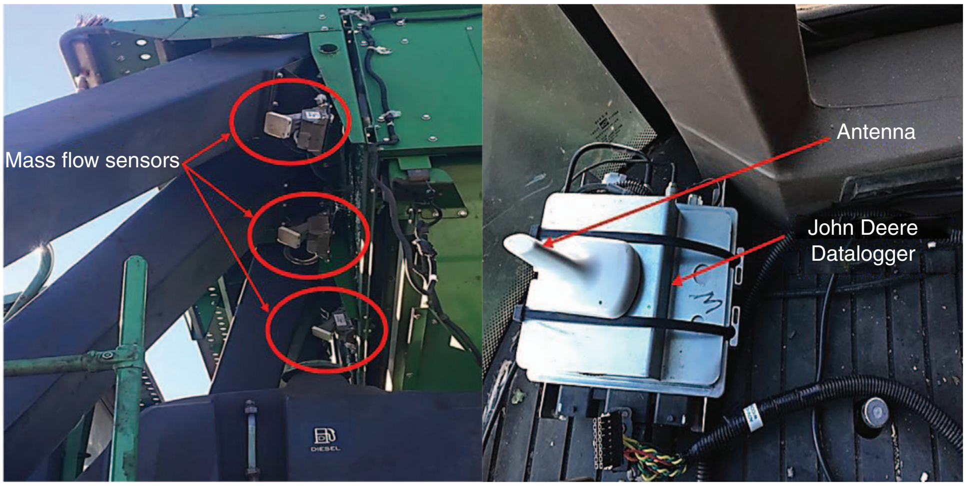

Fig. 4. Mass Flow Sensors and the John Deere-Datalogger.

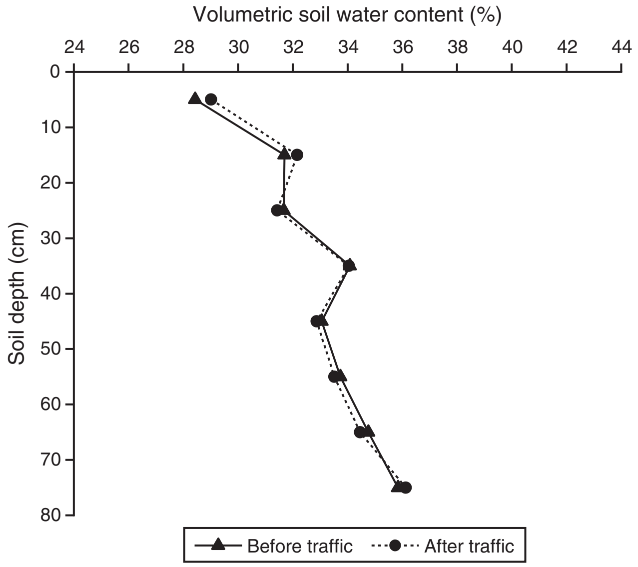

Fig. 5. Volumetric soil water content (%) before and after JD7760 standard configuration traffic in Row 1 at the Undabri site.

Row 1 at Undabri showed a lower Pb before traffic than after traffic, by ~10% in the topsoil, whereas it increased in Row 2 from 1.28 to 1.34 g/cm^3 in the surface soil when compared with before traffic (Fig. 6). A significant increase in Pb was observed in Row 3 after harvest (6%) in the depth of 0–20 cm. The comparison between before and after traffic of the JD7760 standard configuration did not show significant differences in Pb in Furrow 1 throughout the 0–80-cm soil depth. Traffic from the JD7760 caused significant compaction, resulting in increased Pb in Furrow 2 and Furrow 3 for the 0–80-cm depth.

ANOVA analysis of field data showed that traffic from the CTF7760-modified configuration caused no significant difference in Pb in Row 1 throughout the 0–80-cm soil depth. The results also showed that Pb increased significantly in Row 2 and Row 3, from 1.18 to 1.24 g/cm^3 and from 1.29 to 1.35 g/cm^3 in the 0–10-cm and 0–30-cm depths respectively (Fig. 7). Furrow 1 and Furrow 2 did not show a significant difference in Pb throughout the 0–80-cm depth after traffic. Furthermore, one pass from the CTF7760 caused significant compaction in Furrow 3, which resulted in an increase of Pb from 1.42 to 1.52 g/cm^3 for the 0–80-cm depth.

Soil penetration resistance

Overall, soil penetration resistance (SPR) showed a similar trend to Pb across the study fields. The results showed that SPR significantly increased in Row 1, Row 2 and Row 3 at Undabri after harvester traffic, by 61%, 50% and 71% for the 10–20-cm, 10–40-cm and 0–30-cm depths (Fig. 8). Furrow 1 under RTF system did not show any significant difference in the SPR for the 0–70-cm soil depth after traffic. Furthermore, one pass from the JD7760 standard caused significant compaction that led to an increased SPR in Furrow 2 and Furrow 3, by approximately by 60% and 30% at the depth of 0–70 cm.

There was no change in SPR in Row 1 after one pass of the CTF7760 at Yambacully throughout the depth profile, whereas the values of Row 2 and Row 3 showed a significant increase by 90% for the 0–10-cm and 0–30-cm depths when comparing before and after harvester traffic (Fig. 9). Examining the before and after traffic under CTF system demonstrated no differences in the SPR in either Furrow 1 or Furrow 2 throughout the profile depth, whereas a significant compaction was found in Furrow 3 after harvest traffic, which led to an increased SPR to ~3444 kPa at the depth of 60 cm.

Cotton yield

The CAN-BUS data showed that the yield in cotton rows varied between 6.63 and 7.14 bales/ha at Undabri. The yield was significantly higher in Row 1 (7.14 bales/ha) than in Row 2 (6.45 bales/ha) and Row 3 (6.63 bales/ha) respectively (Fig. 10). There was much less difference in yield between

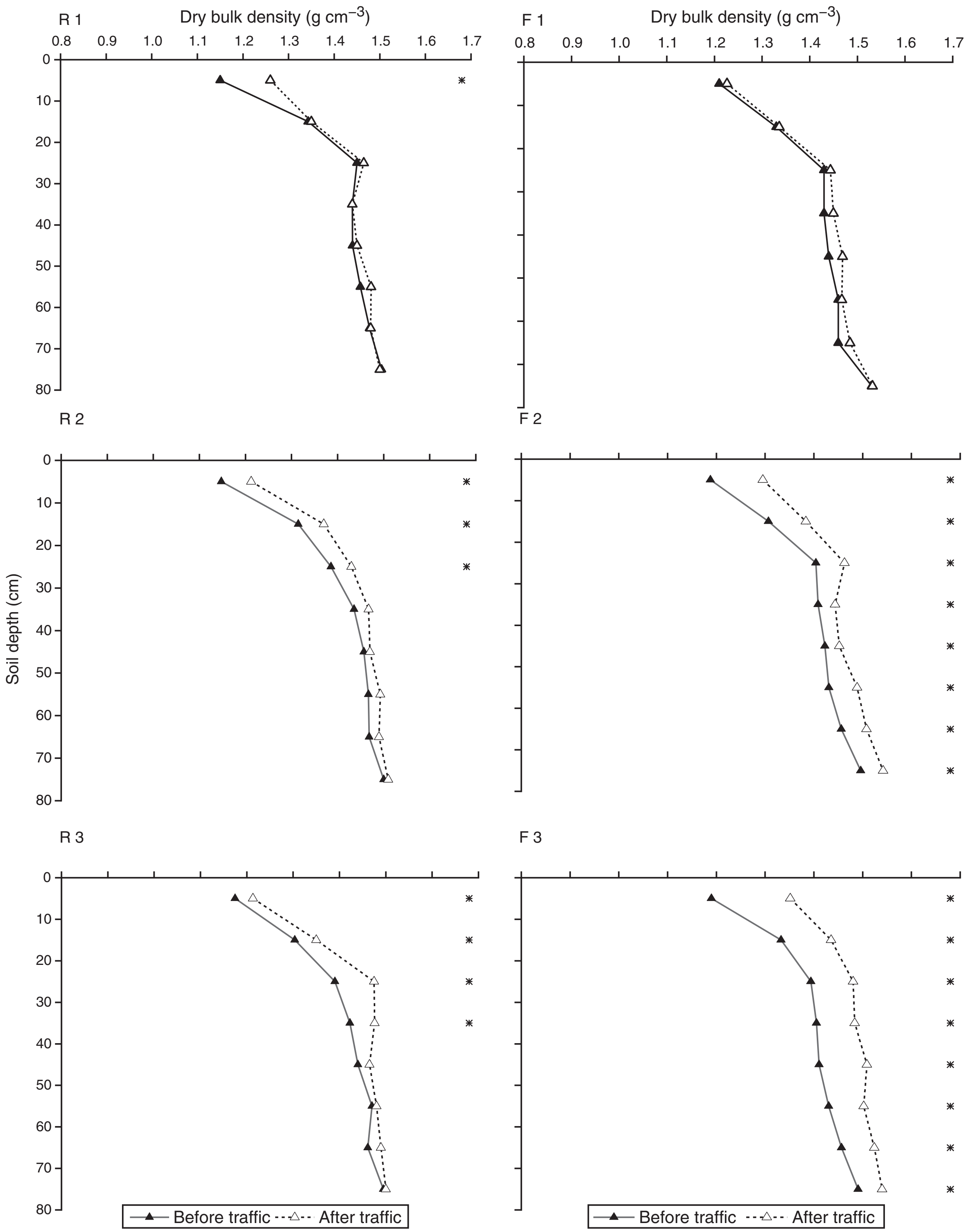

Fig. 6. Before and after traffic comparison in Pb at individual cotton rows and furrows at Undabri.

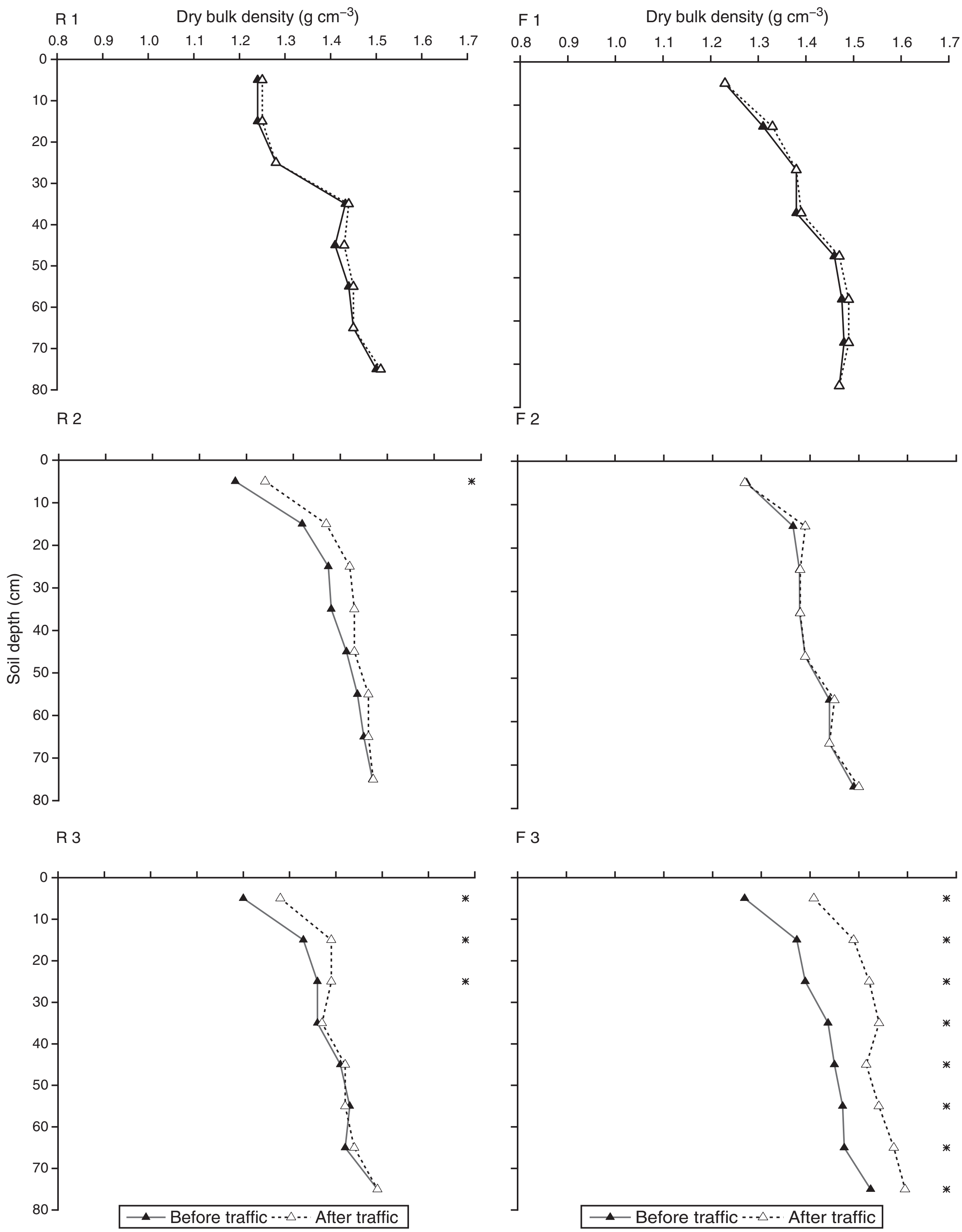

Fig. 7. Before and after traffic comparison in Pb at individual cotton rows and furrows at Yambacully

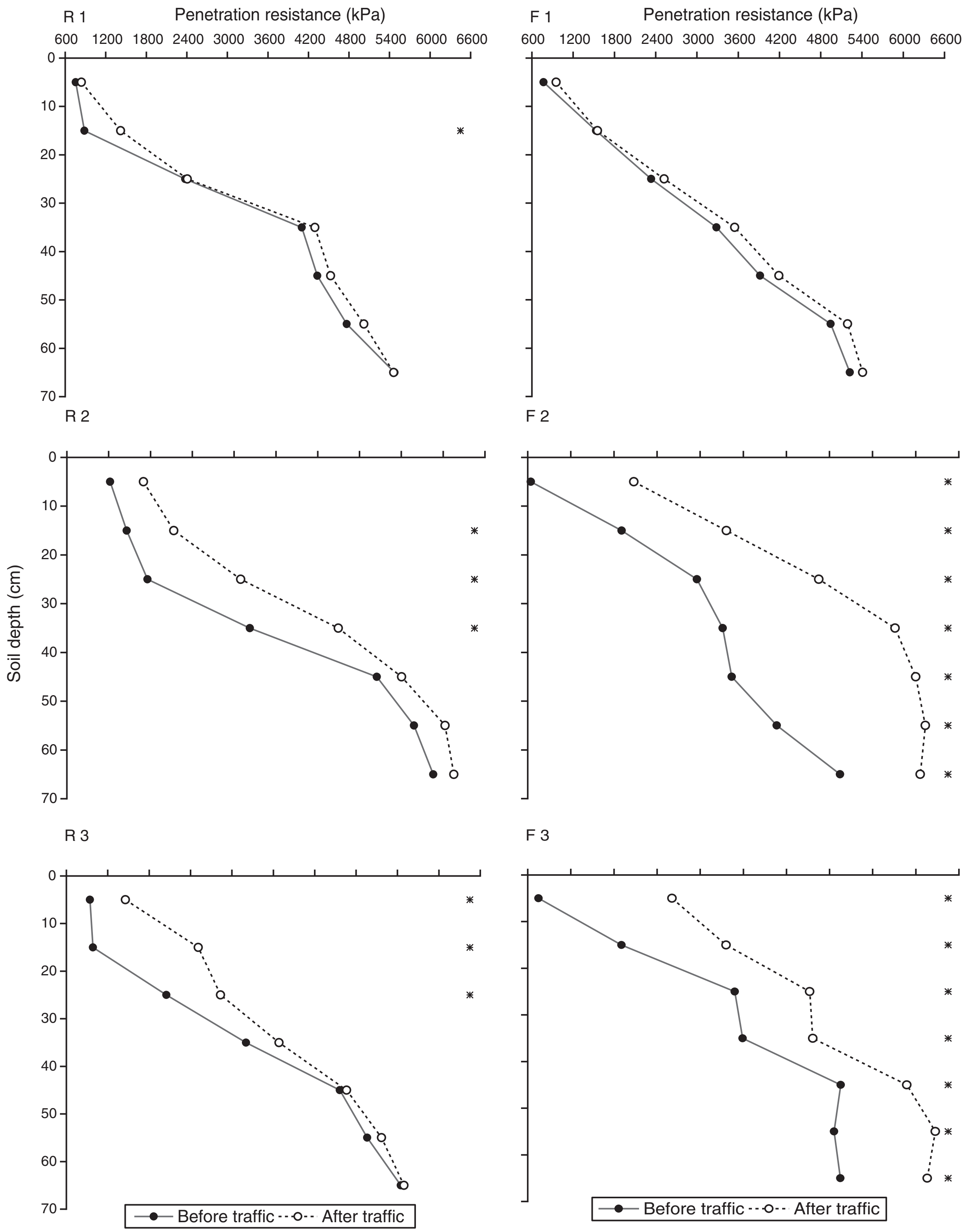

Fig. 8. Effect of the JD7760 traffic on soil penetration resistance at Undabri

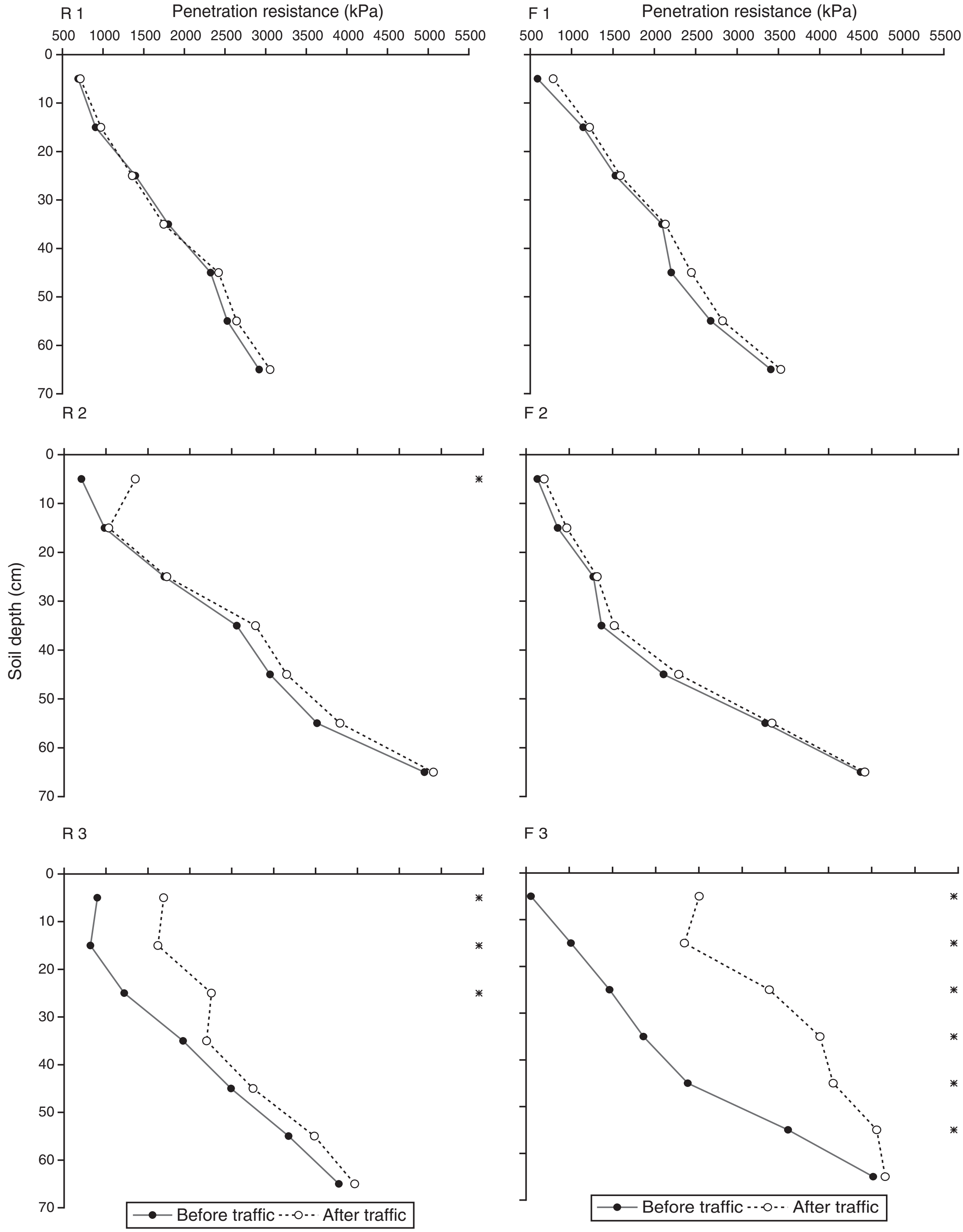

Fig. 9. Effect of the CTF7760 on soil penetration resistance at Yambacully.

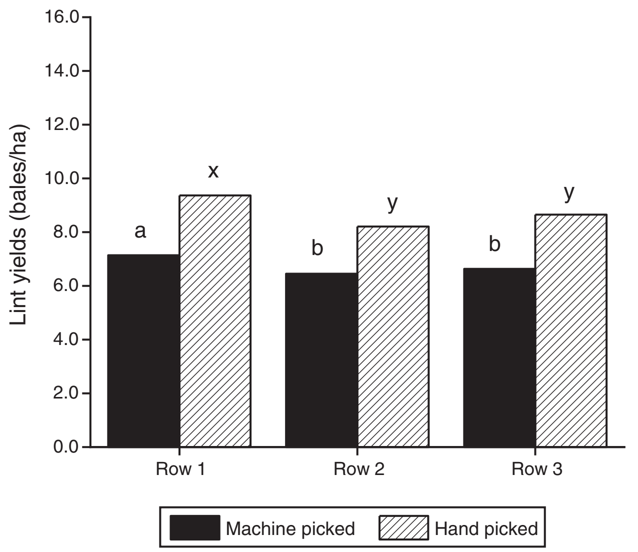

Fig. 10. Individual cotton lint yields (bales/ha) harvested by the JD7760 standard configuration and by hand at Undabri. Different lowercase letters in the figure refer to the significant difference at P = 0.05 level between rows under the machine-picked (a and b), or hand-picked (x and y) method.

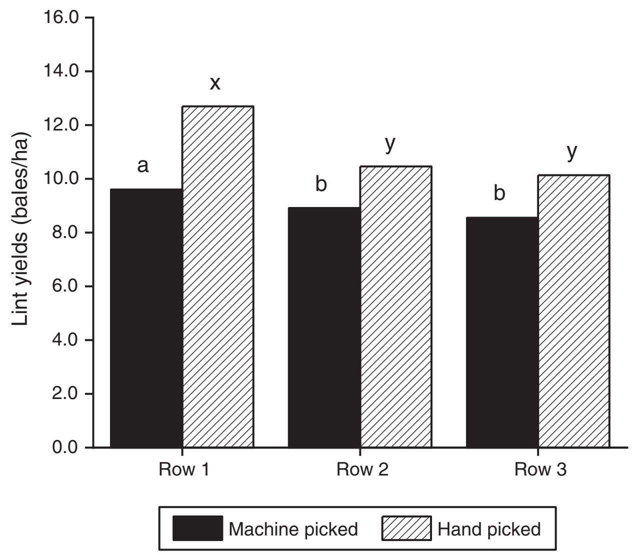

Fig. 11. Individual cotton lint yields (bales/ha) harvested by the JD7760 modified configuration and by hand at Yambacully. Different lowercase letters in the figure refer to the significant difference at P = 0.05 level between rows under the machine-picked (a and b), or hand-picked (x and y) method.

Row 2 and Row 3. The hand-picked method showed a higher yield in Row 1 (9.37 bales/ha) than in Row 2 (8.21 bales/ha) and Row 3 (8.65 bales/ha; Fig. 10). The comparison between Row 2 and Row 3 again did not show any difference.

The Yambacully site produced a higher yield in Row 1 (9.60 bales/ha) than in Row 2 (8.91 bales/ha) and Row 3 (8.55 bales/ha) for machine-picked harvest. Furthermore, hand-picked harvest also showed that Row 1 (12.70 bales/ha) achieved a higher yield than did Row 2 (10.46 bales/ha) and Row 3 (10.14 bales/ha) respectively (Fig. 11). No difference in the yield was observed between Row 2 and Row 3 for the two methods.

Discussions

Impact of the JD7760 traffic on moisture content, dry density and soil strength

The Vertosol soil type has weaknesses in terms of its structural stabilisation of the water and slow infiltration rates that are related to heterogeneity and clay mineralogy (Ghosh *et al.* 2010). As expected, there was no significant effect of harvester traffic in the soil water content across all treatments throughout the profile depth for both sites because sampling occurred directly before and after traffic (Bennett *et al.* 2017).

Antille *et al.* (2016) and Bennett *et al.* (2017) found that, with both RTF and CTF, traffic from the JD7760 cotton picker could produce significant compaction. The key differences between those systems were that underneath the CTF harvester, ~50% of furrows were subject to harvester traffic, whereas 66% of furrows were subject to traffic under the JD7760 standard configuration (Bennett *et al.* 2017). Comparative analysis for the Undabri site in terms of affecting the SPR and Pb demonstrated that one single pass of the standard JD7760 resulted in increasing the values in the topsoil in Row 1. In contrast, Row 1 at Yambacully did not show a change either in SPR or dry bulk density throughout the depth profile. From Fig. 2, it can be noted that Row 1 at Undabri was subjected to the effect of the outer dual-wheel traffic, which resulted in an increased SPR and a reduced porosity underneath the wheel track, and spread to reach adjacent cotton rows, whereas the space between Row 1 and the traffic lane under the CTF provided a protection to the soil's structural arrangement (Braunack *et al.* 2012; Bennett *et al.* 2017).

An increase in the SPR and Pb was observed in Row 2 and Row 3 in the surface soil at Undabri and Yambacully, when compared with Row 1. This suggests that Row 2 under RTF was compressed by the dual-wheel after harvest, which had a sufficient wheel load to change the soil structural arrangement, whereas Row 3 was influenced by the combined effect of the inner dual-wheel and rear tyre traffic. This made significant compaction beneath the wheel track and resulted in an increased SPR and expanded to Row 3. Furthermore, the permanent traffic lane under the CTF system was mainly limited between Row 2 and Row 3, therefore resulting in an increased SPR and Pb (McGarry 1996; Braunack *et al.* 2012; Antille *et al.* 2016).

There was no influence of the JD7760 standard traffic in Furrow1 at Undabri throughout the depth profile compared with that before traffic, indicating that Furrow1 was not subject to wheel traffic during the harvest period. The comparison between before and after traffic did not also show an impact of the CTF7760-modified configuration in both Furrow 1 and Furrow 2 throughout the entire profile. This suggests that CTF played a significant role in avoiding compaction occurrence or minimising soil structure damage through restricting traffic lanes (Tullberg 2010; Antille *et al.* 2016). Traffic from the JD7760 standard produced a significant compaction in both Furrow 2 and Furrow 3 at Undabri, down up of 60-cm depth. Following the same trend, significant compaction was observed in Furrow 3 after one single pass of the CTF7760 harvester, compared with before traffic. These indicated that wheeled traffic over the furrows induced significant compaction irrespective of controlled or random traffic approaches (Hamza and Anderson 2005; Bartimote *et al.* 2017).

Effect of compaction on individual row yield

The crop yield can provide a good indication of the compaction state. More than one-third of the actual yield may be lost when soil structure is damaged by compaction (Daniells 1989). The standard and CTF JD7760 harvesters induce comparable compaction; however, the standard system affects 17% more land because of the dual-wheel system (Bennett *et al.* 2017). Adoption of CTF can reduce the cropped regions affected by traffic by more than 50% (Galambosova *et al.* 2017). In fact, one of the key motivations for the adoption of CTF is that it minimises the area of soil compaction and ensures the maintenance of soil properties of the cultivated portions of the farm, thereby enhancing crop yield and reducing energy requirements (Kingwell and Fuchsbichler 2011; McPhee *et al.* 2013; Chamen *et al*. 2015; ACTFA 2017). In this study, Row 1 at Undabri achieved a higher yield (7.14 bales/ha) than did Row 2 (6.45 bales/ha) and Row 3 (6.63 bales/ha), whereas no significant difference in the yield was observed between Row 2 and Row 3. It can be seen that in the random traffic system, the surface soil in Row 2 was most influenced by harvester traffic. This resulted in significantly changed soil characteristics owing to the effect of the inner and outer dual-wheel harvester traffic. This prevented roots from growing and led to a reduction in water infiltration and nutrient uptake, hence producing the lowest yield when compared with Row 1 and Row 3.

Under CTF, dedicated permanent lanes are used year-in and year-out, restricting machinery passage to specific uncultivated paths (Tullberg *et al.* 2007; Antille *et al.* 2016). CTF with a 1.5-m row spacing is currently used by the Australian cotton industry to avoid the risk of compaction and to improve cotton production (Tullberg *et al.* 2007; Tullberg 2010; Antille *et al.* 2016; Bennett *et al.* 2019). Adopting 1.5-m row spacing under CTF may restrict soil compaction to only 15–20% of the total area (Antille *et al.* 2016; Bartimote *et al.* 2017; Bennett *et al.* 2019). In addition, 1.5-m row spacing might achieve higher cotton yields by 30% after several years of adoption (Quigley *et al.* 2015; Bartimote *et al.* 2017). In this study, Row 1 at Yambacully showed a higher yield (9.60 bales/ha) than did Row 2 (8.91 bales/ha) and Row 3 (8.99 bales/ha), whereas there were no significant differences in the yield between Row 2 and Row 3. This was because that the space between Row 1 and the traffic lane provided a good soil structural arrangement. In contrast, the permanent traffic lanes were mainly between Row 2 and Row 3, which have directly affected crop performance and resulted in a lower yield than for Row 1 (Braunack *et al.* 2012; McPhee *et al.* 2015; Bennett *et al.* 2017). It seemed that cotton rows between the dual-wheels were more affected by compaction than were those neighbouring the wheel track, thus showing the lowest cotton yield (Fig. 12).

Conclusions

Row-by-row Vertosol soil compaction as a result of JD7760 cotton picker traffic and its impact on cotton yield under different row configurations was investigated in this study. It was found that wheel traffic resulted in changing soil properties in the different cotton rows that were between, neighbouring, and underneath the wheel track in the surface and subsurface layers, at both sites. At Yambacully, Row 1 was largely not influenced by harvester traffic and showed the lowest SPR and Pb throughout the depth profile. Row 2 and Row 3 were influenced by harvester traffic at both sites in the top 30-cm depth. Row 2 was the most sensitive to the effect of dual-wheel traffic, which resulted in a higher SPR and density in the surface soil. Wheeled furrows at both sites were sensitive to harvester traffic, which showed a significant compaction in the 0–80-cm depth compared with that before traffic. Row 1 achieved the highest yield at Undabri and Yambacully when compared with other row treatments. Row 2 at the Undabri site produced the lowest yield when

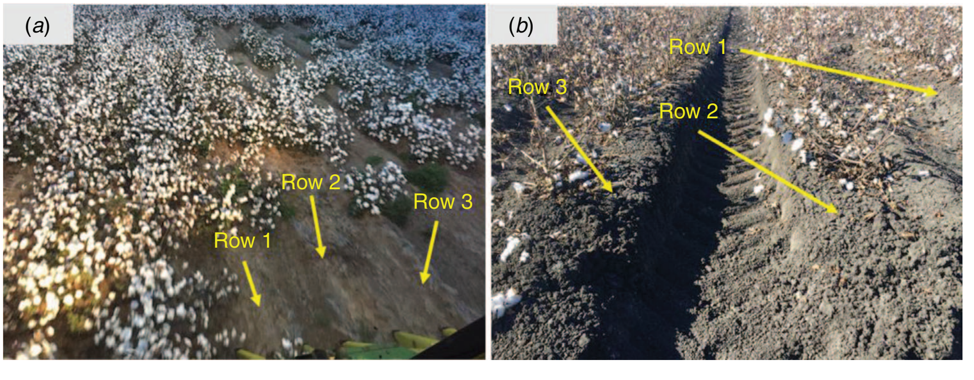

Fig. 12. Cotton row treatments influenced by the JD7760 traffic. (*a*) Undabri under 1.0-m row spacing, and (*b*) CTF Yambacully (1.5-m row spacing).

compared with Row 1 and Row 3. Overall, traffic under CTF conditions provides a good soil structure that can positively reflect on the individual cotton yield. These findings have important implications for farmers intending to grow crops in Vertosol soils and be more specific in their compaction treatments to achieve savings in costs and time.

Conflicts of interest

The authors declare no conflict of interest.

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