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Evaluation of Low Inflation Tire Technologies on Soil Compaction

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Abstract
Evaluation of recent advances in tire technologies such as advanced deflection agricultural tires (Firestone IF and VF) and precision tire inflation technologies on soil compaction, traction, fuel economy and crop yield responses are important. The purpose of the study was to investigate the effects of field and transport (road) tire inflation pressure settings of row-crop agricultural tractor and planter tires on soil compaction. A randomized complete block design experiment was conducted at the Iowa State University farm at Boone, Iowa for two tire inflation pressure levels on Dual Front (Firestone IF 420/85R34) and Dual Rear (Firestone IF 480/80R50) tires on a John Deere 8310R MFWD tractor, and transport tires (Super single 445/50R22.5) on a John Deere DB60 planter. Soil compaction was measured using Stress State Transducers (SSTs) buried at 15-cm and 30-cm depths beneath the untrafficked soil surface. The soil cone index depth profile was measured at tire-centerline, tire-edge and 20 cm laterally outboard of the tire edge before and after tractor-planter tire passes. Peak Octahedral Normal Stress (ONS) and the corresponding Octahedral Shear Stress (OSS) values in soil were calculated from the SST data. The peak ONS and corresponding OSS values from the road tire inflation pressure settings were statistically higher (p-value < 0.05) than the field tire inflation pressure settings. The maximum ONS was observed at 15 cm soil depth from the road tire inflation pressure setting of the rear tractor tires (179 kPa tire inflation pressure and 33 kN load per tire). The ONS from the front tractor tires (138 kPa tire inflation pressure and 17 kN load per tire) and planter transportation tires (620 kPa tire inflation pressure and 16.5 kN load per tire) were similar. Cone index data also showed significant differences, comparing before and after tires passes, at the tire-centerline. The peak cone index values for the 0 to 100 mm soil depth range were 1.3 MPa and 1.2 MPa from the road and field tire inflation pressure settings, respectively.

Keywords
Soil Compaction, Soil stress state, Cone Index, Precision Tire Inflation

Disciplines
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Comments
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Evaluation of Low Inflation Tire Technologies on Soil Compaction

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ABSTRACT. *Evaluation of recent advances in tire technologies such as advanced deflection agricultural tires (Firestone IF and VF) and precision tire inflation technologies on soil compaction, traction, fuel economy and crop yield responses are important. The purpose of the study was to investigate the effects of field and transport (road) tire inflation pressure settings of row-crop agricultural tractor and planter tires on soil compaction. A randomized complete block design experiment was conducted at Iowa State University farm in Boone, Iowa for two tire inflation pressure levels on Dual Front (Firestone IF 420/85R34) and Dual Rear (Firestone IF 480/80R50) tires on a John Deere 8310R MFWD tractor, and transport tires (Super single 445/50R22.5) on a John Deere DB60 planter. Soil compaction was measured using Stress State Transducers (SST) buried at 15-cm and 30-cm depths beneath the untrafficked soil surface. Cone index depth profile was measured at tire-centerline, tire-edge and 20 cm laterally outboard of the tire edge before and after tractor-planter tire passes. Peak Octahedral Normal Soil Stress (ONSS) and the corresponding Octahedral Shear Soil Stress (OSSS) values were calculated from the SST data. The peak ONSS and OSSS values from the road tire pressure settings were statistically higher (p-value < 0.01). The maximum ONSS was observed at 15 cm soil depth from the road tire inflation pressure setting of the rear tractor tires (179 kPa tire inflation pressure and 25 kN load per tire). The ONSS from the front tractor tires (138 kPa tire inflation pressure and 17 kN load per tire) and planter transportation tires (620 kPa tire inflation pressure and 16.5 kN load per tire) were similar. Cone index data also showed significant differences, comparing before and after tires passes, at the tire-centerline. The peak cone index values were 1.3 MPa and 1.2 MPa from the road and field tire inflation pressure settings, respectively.*

Keywords. *Soil Compaction, Soil stress state, Cone Index, Precision Tire Inflation.*

Introduction

Soil compaction often restricts root growth with potential crop yield reduction and could also accelerate environmental soil quality degradation in the forms of increased soil erosion and runoff. Modern agricultural farm equipment keeps getting bigger in size along with the concerns on soil compaction from excessive axle loading on compactable soil conditions. According to Iowa State University extension report (PM1901B, 2015) and IOWA Department Of Transportation (DOT) (PM-778, 2015) axle loads from modern tractor, combine with full grain tank, grain carts (850-bushel capacity) and liquid manure tank (10,000 gallon capacity) exceed the 10-metric ton axle load on single axle limits for deep soil compaction and road infrastructure carrying capacities. Tire manufactures are introducing advanced deflection agricultural tires such as Firestone Advanced Deflection Design (AD^2) “IF” and “VF” new tire standard designations that could carry 20% (IF) to 40% (VF) higher vertical load over the standard radial ply wheel tires at the same pressures (Firestone D-670,2015), respectively or operate at lower tire inflation pressure to increase tire-soil footprint for improving tractor performance and productivity (traction efficiency and fuel consumption), and reduced soil compaction. Similarly precision tire inflation technologies such as Central Tire Inflation System (CTIS) (Tigges, 2015) have been introduced to precisely apply tire inflation pressures for road and field conditions for improving traction, fuel use, longer tire life, reduced soil compaction, increased traction efficiency, and operator comfort. Harris and Rethmel (2011) conducted laboratory tire deflection tests and flat plate foot print area measurement using Tekscan pressure sensing sensors on IF and standard radial ply metric drive wheel agricultural tires Firestone 480/80R50 and 710/70R42 agricultural tires. IF 480/80R50 and IF 710/70R42 tires showed benefits over same size standard radial tires with higher deflection of tire section height by 20% over wide range of vertical loads and tire inflation pressures. Approximately 13% increase on contact area was measured from IF 480/80R50 (tire inflation pressure at 17 psi) compared with standard 480/80R50 (tire inflation pressure at 22 psi) vertically loaded at 7000 pounds. In controlled traction tests with operating slip range between 5 to 15 % typical for agricultural tractors, Harris and Rethemel (2011) have shown improved traction up to 13% to 17% and vehicle fuel saving from the IF tires compared with standard radial tires.

With the combination of precision tire inflation pressure control from Central Tire Inflation Systems (Tigges, 2015) and advanced deflection tire technologies, the tire inflation pressure on tractor and implements tires can be regulated depending on axle load and operation conditions (field or road), the desired tire performance, productivity of agricultural machine and reduced soil compaction can potential be achieved. Limited studies have been done on measurement soil compaction (surface and subsoil layers), traction, fuel economy and crop yield responses that will evaluate new tire and inflation pressure control technologies. The objective of the study was to investigate the effects of tire inflation pressure on row crop tractor IF tires and super single planter tires on soil compaction measured from soil stress state and soil cone index. The outcome of the research will help to define precision tire inflation settings for maximizing tractor performance and reduce soil compaction on field and road (transport) operations.

Materials and Methods

Site Description

The experiment was conducted during Fall 2016 at the Iowa State University farm in Boone, Iowa located at a latitude 42^0 1′ 15″N and a longitude 93^0 45′ 32″W on 4 hectare plot. The field was disked at 5-mph using John Deere 510 Disk Ripper and cultivated using John Deere 2210 Cultivator at 100-mm depth and 6-mph to prepare seedbed tillage conditions. Loam and clay loam are the dominant soil types in the field plot according to USDA soil survey (http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx).

Tractor-pulling planter with full Central Commodity System (CCS) seed cart (455-kg of corn) was run perpendicular to the tillage direction. A randomized complete block design experiment with two tire inflation pressure settings (“Field” for low tire inflation pressure and “Road” for high tire inflation pressures) in three replications was conducted at Iowa State University farm in Boone, Iowa. The two tire inflation pressure settings as recommend by manufacturer values were monitored for the Dual Front Firestone IF 420/85R34 R1-W Radial All Traction DT and Dual Rear Firestone IF 480/80R50 R1-W Radial Deep Tread 23^0 tires on a John Deere 8310R MFWD tractor, and transport tires (Super single 445/50R22.5) on a John Deere DB60 planter 60-ft. toolbar with 47 split rows on 15-in. spacing. The Central Commodity System (CCS) was full to reproduce the maximum axle load on the planter transport tires. A vertical down force of 200-lbf (890 N) was applied on the row units expected the units behind the four transport tires to reproduce typical spring planter settings. The forward travel speed was 5-mph with Tractor MFWD engaged.

(A)

(B)

Figure 1. (A) John Deere 8310R MFWD tractor. Front: Dual Firestone IF 420/85R34 R1-W Radial All Traction DT. Rear: Dual Firestone IF 480/80R50 R1-W Radial Deep Tread 23° and (B) John Deere DB 60 foot toolbar planter, 47 split-row with 15-in. spacing. Planter tires: Super single 445/50R22.5. During test the row units behind the planter transport tires were up to minimize rut depth measurement error.

Table 1. Tractor and planter information loaded with grain full CCS (2345-kg) and tractor-planter in transport position with planter wing tire lifted in up position.

Tractor	Brand	John Deere
	Model	JD 8310R MWFD
	Rate HP Engine (Gross)	310
	Total Machine Weight (kg)	19,741
	Front Axle Weight (kg)	6,196
	Rear Axle Weight (kg)	13,546
Planter	Brand	John Deere
	Model	DB 60 60-ft. toolbar with 47 split rows on 15-in. spacing
	Transport Tires Axle Weight in Transport position (kg)	12,477
	Transport Tires Axle Weight in Field position (kg)	12,205
	Wing Tires Axle Weight in Field position (kg)	3,977

Experimental Design of Experiment

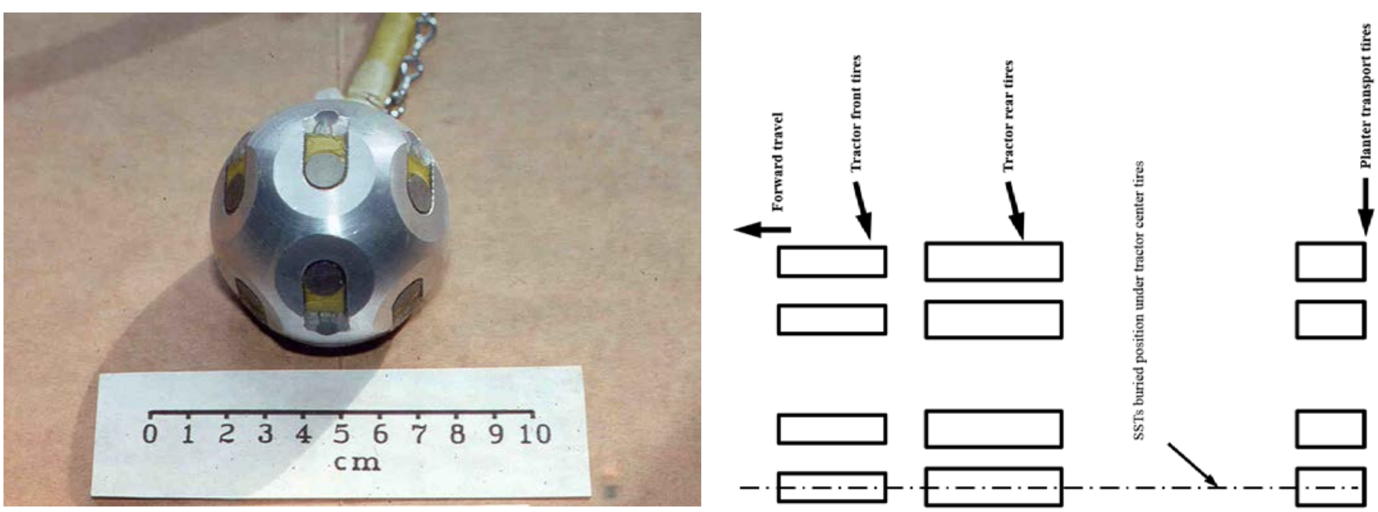
The main factor for the randomized complete block design experiment was tire inflation pressure on tractor-planter configuration. One factor setting was the road tire inflation pressure configuration for Tractor tires and transport planter tires. Two tire inflation pressure settings that were designated as “road” for high standard tire inflation setting and “field” for low IF tire inflation setting. The tire inflation pressures values were given from Firestone recommendations based on the measured vertical loads (Table-1) on the IF tractor tires and super single planter transport tires and inflation pressure combinations for “road” (high) and “field” (low) settings. Table -2 shows the design of experiment with the “road” and “field” tire inflation pressure treatments on the tractor and transport planter tires. The treatments and replicate combinations are randomly assigned on the field plots. Each plot had a width of 17.7-m (47 rows 15-in. spacing).

Table 2. The design of experiment for tractor and planter tire inflation pressures.

Run#	Treatement/Replicates	Tire Inflation	Tractor Tire (psi)	Planter Transport Tires (psi)
1	T1R1	ROAD	FRONT = 20 REAR = 26	90
2	T1R2	ROAD	FRONT = 20 REAR = 26	90
3	T1R3	ROAD	FRONT = 20 REAR = 26	90
4	T2R1	FIELD	FRONT = 12 REAR = 9	29
5	T2R2	FIELD	FRONT = 12 REAR = 9	29
6	T2R3	FIELD	FRONT = 12 REAR = 9	29

Soil Stress Transducers (SSTs) for soil stress measurement

Soil stress states beneath tire were measured using Stress State Transducers (SSTs). EDAQ somat data acquisition (Somat Series 2000 Field Computer System,) was used to acquire from six normal pressure activing on six planes of the SSTs at 20Hz. The SSTs were buried at 15-cm and 30-cm beneath the outer tire center line measuring the soil stress states from tractor outer tire and planter transport tire passes.



(A) (B)

Figure 2. (A) Soil State Transducers (SSTs) used in the experiment (six axis 345 kPa pressure sensors) and (B) position of SSTs buried beneath the centerline of the path of the outer left tractor and planter transport tires. The SSTs were buried at 15-cm and 30-cm beneath the untrafficked soil surface.

Before and after tractor-planter tire passes, soil cone index was measured surface to 600-mm at 15-mm sampling interval using a cone penetrometer (Rimik CP-20, Agridyr Rimik Pty, Ltd., Toowomba, Australia) and ASABE standard cone and procedure (apex angle = 30 º, cone base diameter d = 12.8 mm and shaft diameter d-shaft = 9.53 mm) (ASAE standards S313.3, 1999a and EP 542, 1999b). Soil core samples (40 mm height by 69-mm dimeter) were collected before and after tire passes at 15-cm and 30-cm soil depth from untrafficed soil surfaces at tire center line to determine the soil bulk density and soil moisture content. The soil cone index and soil core samples before tire passes were taken on the untrafficked soil surface. The soil samples were oven dried at 105ºc for 72 h to determine the dry soil bulk density and gravimetric soil moisture content. The cone index sampling positions for before and after tire passes are shown in Figure-3. For each positions, three replicates of cone penetrometer measurement were taken. After tire passes rut depth and rut width were measured using graduated ruler.

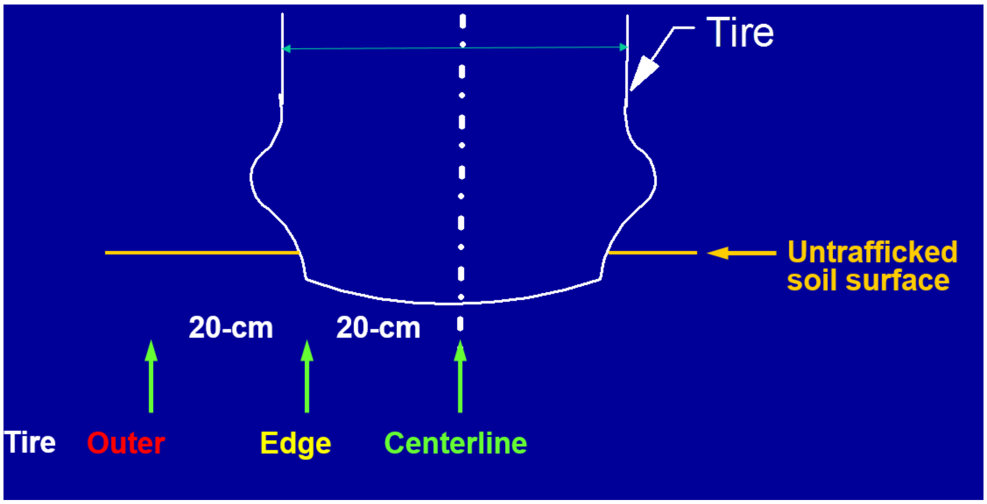


Figure 3. Soil cone index measurement sampling positions for before and after tire passes.

Drawbar pull

The drawbar pull from tillage and planting operation was measured 133 kN capacity load cell transducer attached to the John Deere 8310R tractor drawbar toolbar.

Data Analysis

The SSTs data measured from six pressure sensor data normal to the SSTs unique planes were analyzed to calculate the peak value of Octahedral Normal Soil Stress (ONSS) and the corresponding Octahedral Shear Soil Stress (OSSS) according to Bailey et al., 1996. On their study to investigate soil stresses from tractor tire at various dynamic loads and inflation pressure, Bailey et al., 1996 found the peak value of Octahedral Normal Soil Stress (ONSS) and the corresponding Octahedral Shear Soil Stress (OSSS). The peak values of Octahedral Normal Soil Stress (ONSS) and the corresponding values of Octahedral Shear Soil Stress (OSSS) were analyzed using GLM procedure in SAS Ver. 9.4 (SAS, 2013).

Results and Discussion

Soil Stress States

Figure 4 showed example of the soil stress state data from the SST sensor from the tractor and planter tires passes. For the tire inflation pressure comparison, only the peak Octahedral Normal Soil Stress (ONSS) and the corresponding Octahedral Shear Soil Stress (OSSS) (Fig. 5 and 6) were used. The maximum ONSS was observed at 15 cm soil depth from the road tire inflation pressure setting of the rear tractor tires (179 kPa tire inflation pressure and 25 kN load per tire). The ONSS from the front tractor tires (138 kPa tire inflation pressure and 17 kN load per tire) and planter transportation tires (620 kPa tire inflation pressure and 16.5 kN load per tire) were similar. Statistical analysis (with p-value = 0.01 as significant level) on the peak ONSS assuming the soil depth repeated variables and tire inflation pressure main treatment effects, the soil depth strongly affected (P = 0.0005) the peak ONSS stress with the higher values at 15-cm soil depth. The interaction effect of SSTs depth and tire inflation pressure was not statistically significant (P = 0.117). Averaged by SSTs depths, the average peak ONSS from “road” (high) (2.78 psi) tire inflation pressure tractor-planter configuration was twice as high as the average peak ONSS from “field” (low) (1.28 psi). This implied tractor-planter tire inflation pressure set for lower inflation pressure will have less soil compaction problem compared to the currently utilized standard tire inflation pressure. At wet soil moisture conditions, this negative effect will likely get higher. As shown in Figure-6, the corresponding

Octahedral Shear Soil Stress (OSSS) showed similar trend to the ONSS for the two soil depth and the tire-inflation pressure settings where the maximum OSSS occurred at 15-cm and "road" (high) tire inflation pressure. According to Bailey and Johnson (1989) soil compaction model, the ONSS accounts for majority of soil compaction from their triaxial cylindrical test data.

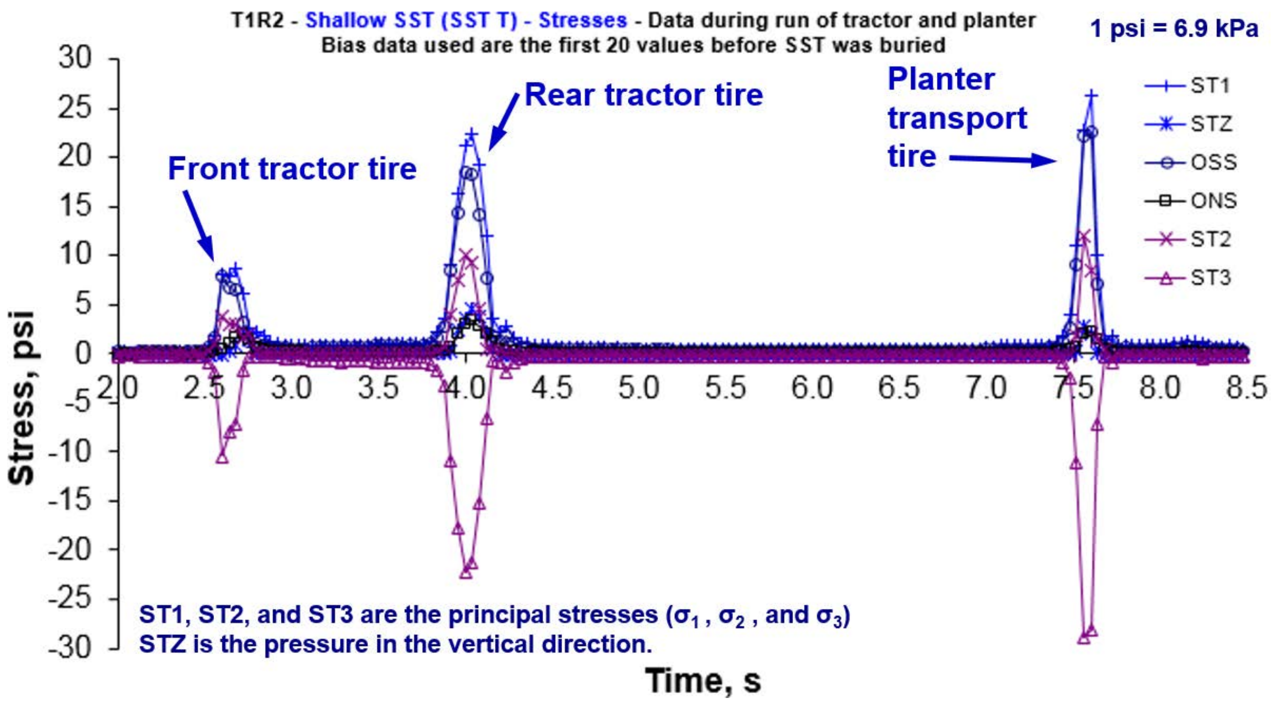
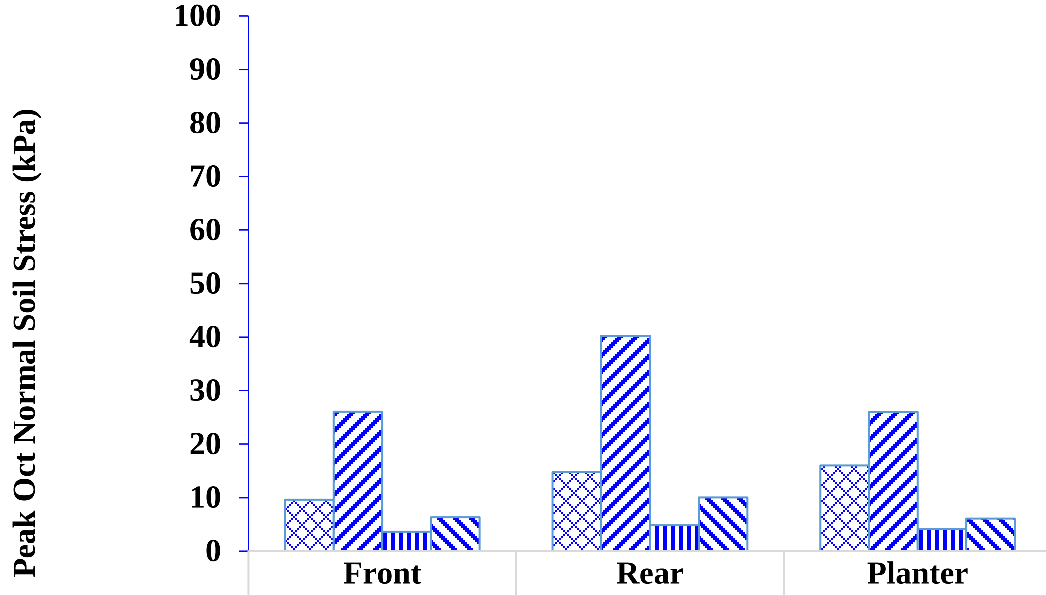
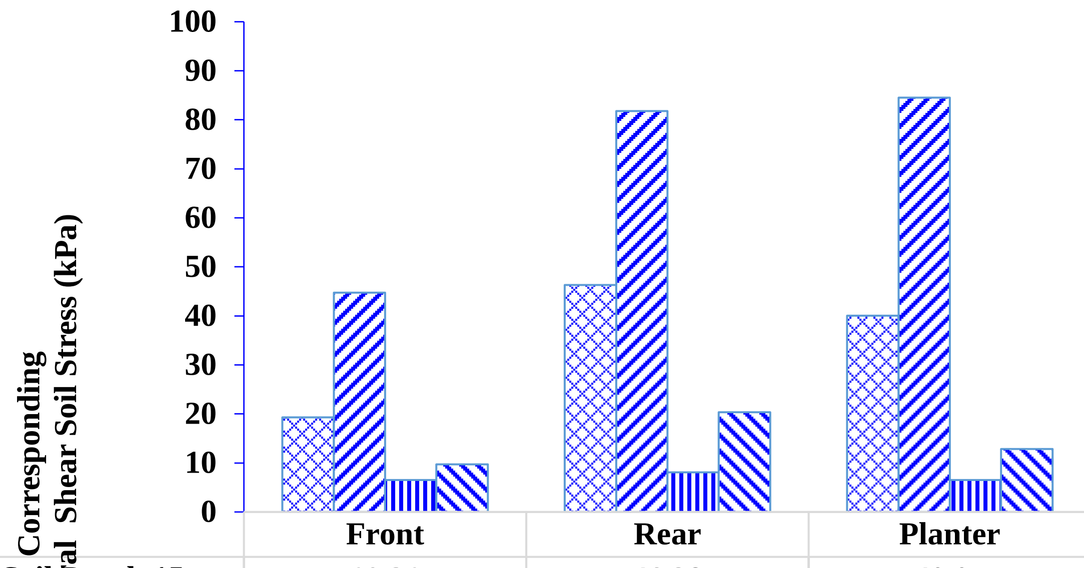


Figure 4. Soil stress states calculated from SSTs pressure data. ST1, ST2, ST3 are the principal stresses (sigma-1, sigma-2, sigma-3) and STZ vertical stress. ONS is Octahedral Normal Soil Stress and OSS is Octahedral Shear Soil Stress.



	Front	Rear	Planter
Field_Soil Depth 15-cm	9.61	14.75	16.01
Road_Soil Depth 15 cm	26.07	40.26	26.00
Field_Soil Depth 30 cm	3.62	4.80	4.11
Road_Soil Depth 30 cm	6.34	10.03	6.09

Figure 5. Mean of three replicates peak Octahedral Normal Soil Stress (ONSS) for 'field" (low) and "road" (high) tire inflation pressures at 15-cm and 30-cm soil depths from tractor front, tractor rear and planter transport tires.



	Front	Rear	Planter
Field_Soil Depth 15 cm	19.31	46.28	40.05
Road_Soil Depth 15 cm	44.75	81.79	84.52
Field_Soil Depth 30 cm	6.53	8.07	6.54
Road_Soil Depth 30 cm	9.71	20.34	12.87

Figure 6. Mean of three replicates corresponding Octahedral Shear Soil Stress for 'field" (low) and "road" (high) tire inflation pressures at 15-cm and 30-cm soil depths from tractor front, tractor rear and planter transport tires.

Soil Cone Index

The soil cone index showed differences among the tire center and edge positions and tire inflation pressure treatment levels. For the 0-100 mm soil depth, the soil cone index after tire passes pronounced differences in soil cone index was observed comparing before and after at the tire-center both for the “field” and “road”. The peak cone index from the “road” was 1300 kPa and higher than the peak from the “field” inflation pressure setting. Below the 100-mm soil depth, the cone index profile does not seem to show trends related to soil cone index position relative to tire and tire inflation pressure settings. At the tire-outer positions where the effect of tire traffic on soil cone index was minimum the cone index profile appear similar among sampling position and treatment factors.

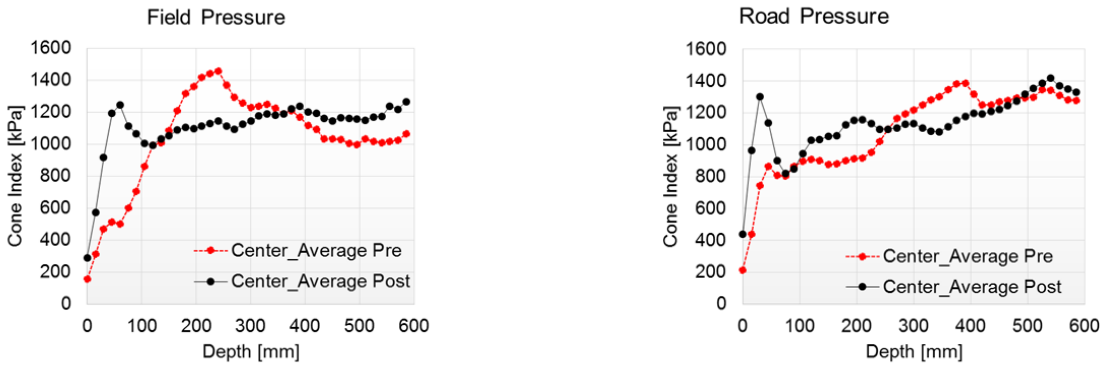


Figure 7. Soil cone index from tire centerline position for “field”(low) and “road” (high) tire inflation pressures. (sample size, n = 3 for each cone index profile).

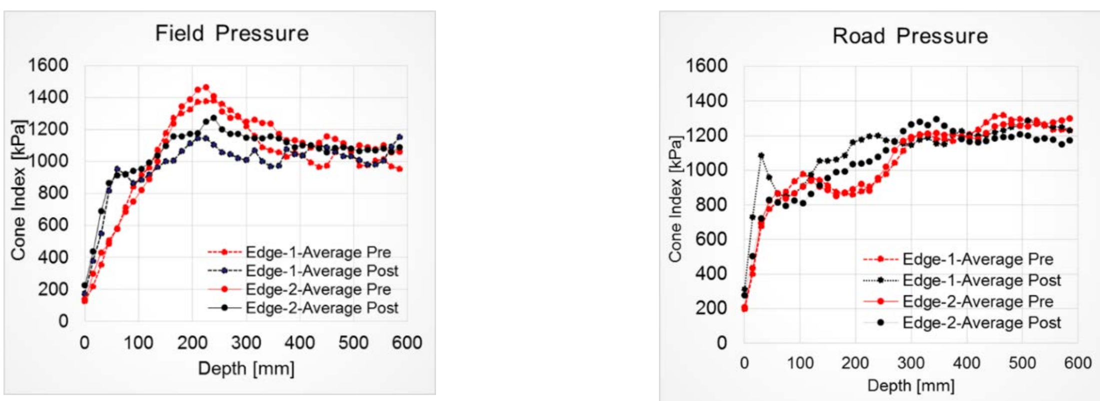


Figure 8. Soil cone index from tire edge position for “field”(low) and “road” (high) tire inflation pressures.

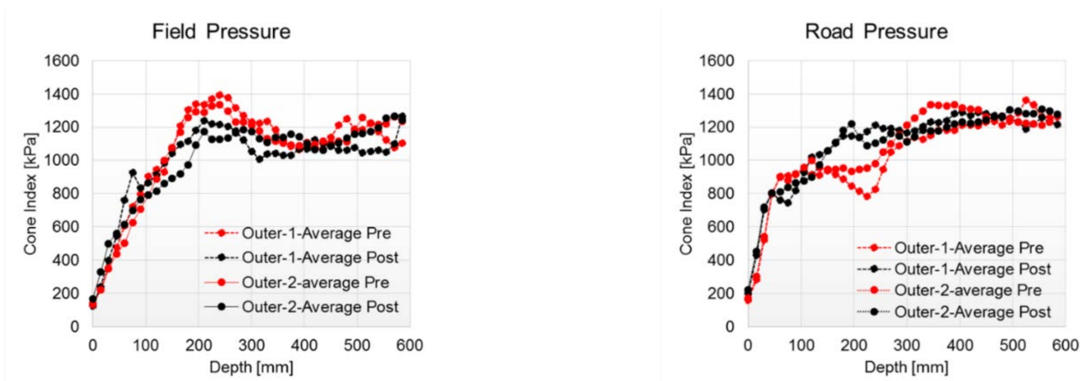


Figure 9. Soil cone index from tire outer position for “field”(low) and “road” (high) tire inflation pressures.

Drawbar pull force

The mean drawbar full force from primary tillage (JD 510 Disk Ripper @12-in tillage depth and 5-mph travel speed) was 60 kN (Stdev = 1kN). For cultivation tillage, the mean drawbar pull from JD 2210 Field Cultivator (26-ft) @4-in. tillage depth and 6-mph travel speed was 40 kN (Stdev = 0.33 kN). From the tractor puling the DB planter, there was not statistically significant differences (P-value 0.0715) in the average drawbar pull force by tire inflation pressure “field” and “road”. The lower drawbar full force from “road” (high) inflation pressure indicate the tractor tires compacted the soil making it lower draft pulling forces of the planter.

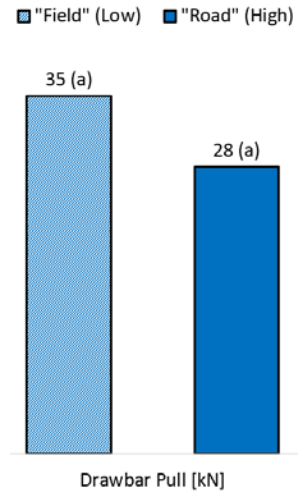
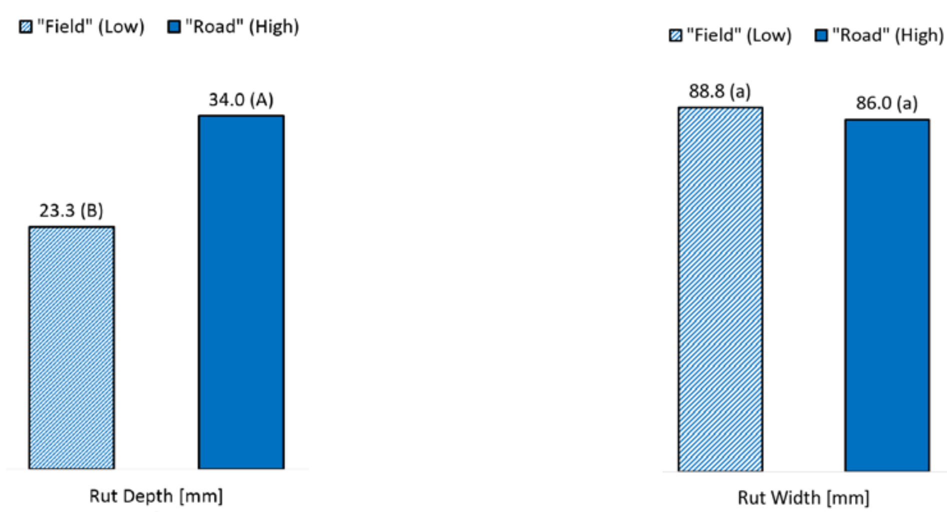


Figure 10. Tractor-planter drawbar pull for “field” (low) and “road” (high) tire inflation pressure. Similar letter indicate no statistical differences at P-value = 0.01. P-value 0.0715 (sample size, n = 3 for each treatment factors).

Soil Rut Depth and Rut Width

The measured rut depth difference (11-mm) between the “road” (high) and “field” (low) tire inflation pressure was statistically higher (P = 0.0005). Rut width from the “field” (low) tire inflation pressure showed slight increase (3-mm) compared to the “road” (high) tire inflation pressure; however it was not statistically significant (p = 0.3212). With less rut depth and increased rut width the “field” (low) inflation pressure setting implied increased tire-soil footprint. Measurement of tire-soil footprint and pressure mat with Tekscan technology may provide additional information on the effects of tire inflation pressure from IF vs standard settings.



(A) (B)

Figure 11. Soil rut depth (A) and soil rut width (B) from “field” (low) and “road” (high) tire inflation pressure after tractor-planter pass (sample size , n = 9 for each treatment factors). For each variables (soil rut depth and soil rut width), similar letter indicate no statistical differences at P-value = 0.01.

Conclusion

Field study of soil compaction from row crop John Deere 8310R pulling John Deere DB60 pulling with CCS was conducted for two tire inflation pressures "road" (high) and "field" (low) on Dual Front and Dual Rear Tractor tires and the Super singles planter transport tires. The "road" tire inflation pressure increased the potential of soil compaction as reported in the values of peak Octahedral Normal Soil Stress (ONSS) and corresponding Octahedral Shear Soil Stress (OSSS); however the differences compared with the "field" (low) tire inflation pressures were not significant (P). The peak ONSS was statistically significant at 15-cm compared with 30-cm with the higher values the "road" tire inflation pressure.

For the 0-100 mm soil depth, comparing before and after tractor and planter tire passes the soil cone index at the tire-center was higher from the "road" (high) and "field" (low). At the tire-edge and tire outer positions, the differences in the soil cone index from the two tire-inflation pressure treatments are minimum. The planter drawbar pull forces from the "road" and "field" tire inflation pressures were not statistically different. Soil rut depth increased as a result of operating at "road" tire inflation pressure compared with the "field" tire inflation pressure.

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