Increased Deflection Agricultural Radial Tires Following the Tire and Rim Association IF, VF, and IF/CFO Load and Inflation Standards

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Increased Deflection Agricultural Radial Tires Following the Tire and Rim Association IF, VF, and IF/CFO Load and Inflation Standards

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Abstract. *Limiting soil compaction has been the focus of tire and track manufacturers as axle loads have increased with larger agricultural equipment. Track manufacturers are increasing track widths and lengths, and adding more mid-rollers to increase footprint area in the attempt to reduce contact pressures. In the past decade tire manufacturers have increased the diameter and width of radial tires to increase the air volume chamber while maintaining the same deflection and keeping operating inflation pressures below 210 kPa (30 psi). In the mid-2000s, the tire industry was close to the maximum allowable diameter of the tire and width regulations of various countries prevented the tires from getting wider. To carry the heavier loads the operational pressures of the tires had to be increased from 210 kPa (30 psi) to 280 kPa (41 psi). The increase in operational pressure could be designed into the tire, but the higher operational pressure increases the contact pressure the ground experiences when the tire traffics the soil. In dry soils the higher contact pressure does not noticeably damage the soil structure. In moist or wet soils, the higher contact pressures reduce pore space, damages soil structure, and cause soil compaction. To help reduce the tire's damage to the soil by lowering inflation pressure, new radial tire standards were developed by the tire industry. These new standards allow the tire to deflect more than a standard radial tire. The IF, VF, and IF/CFO standards increase the load-carrying capacity of the radial tire without increasing the inflation pressure.*

Keywords. *Tires, IF, VF, IF/CFO, Radial, Soil compaction, Increased deflection.*

Introduction

Agricultural equipment manufacturers are focused on producing equipment that allows customers to be more productive while reducing operating costs. These improvements include, but are not limited to, GPS technologies to reduce operator fatigue, larger equipment to cover more acres in a day, and radial tires to improve traction and reduce fuel costs. The larger equipment allows users to get more done in a day and reduce operating costs. When the equipment is used on optimal or dry-soil moistures, the users do not experience any negative agronomic effects. If the equipment is used on wet or saturated soil conditions, users notice a reduction in crop health during stressful growing conditions in the areas where the tires have passed. As the tire passes over the wet or saturated soil, it disturbs the soil structure and increases the density of the soil by reducing the pore space between soil particles. The increased soil density is commonly called soil compaction, and it limits root growth and can limit yield potential.

Research conducted by various universities concluded soil compaction was being caused by the tires used on the equipment. The research also suggests the pressure inside of the tire relates to the amount of pressure being applied to the soil. In a study published by the University of Minnesota (DeJong-Hughes et al., 2001), researchers recorded the ground pressure of various tire sizes inflated at 12 psi. The axle loads increased as the tires got larger and matched the load and inflation tables for all the tires. The research shows the maximum contact pressure the ground experienced was 1 to 3 psi higher than the inflation pressure of the tire (Figure 1). The heavier axle load did distribute the compaction deeper into the soil structure: the experiment did show maximum soil contact pressure can be directly related to tire inflation pressure.

DeJong-Hughes et al., (2001) noted that equipment manufacturers increase the tire size as axle loads increase. This is true, but today the industry is faced with heavier

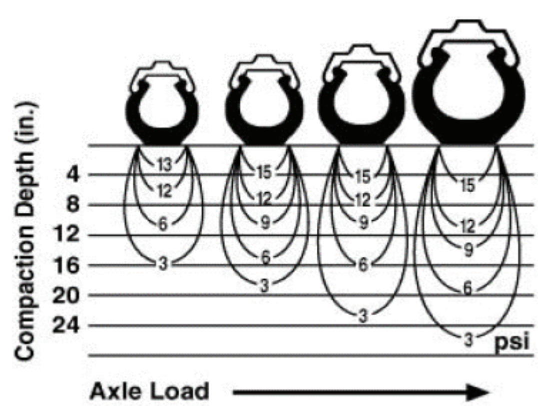

Figure 1. Depth of compaction as axle load increases (tire inflation pressure remained at 12 psi for all tire sizes). Adapted from Soehne, 1958.

Table 1. 20.8-42 and 520/85R42 tire load capacities at common inflation pressures (from Tire and Rim Association, Inc., 2016 Year Book).

20.8-42 vs. 520/85R42 Load Rating				
Inflation pressure (kPa)	80	140	180	220
Bias load (kg)	2300	3150	3650	4125
Radial load (kg)	2575	3750	4250	4625
Load increase of a radial relative to bias (%)	12	19	16	12

equipment and the dimensional window for tires has not increased. To be able to carry the axle loads, the tire industry has been working with equipment manufacturers to move from bias to radial tires.

Bias to Radial Conversion

A radial tire is designed to deflect more than a bias tire. The higher deflection allows the radial tire to carry more load at the same inflation pressure as a bias tire. To illustrate this, compare a 20.8-42 bias tire with a 520/85R42 (20.8R42) radial. In the Tire and Rim Association standard, these tires are the same size, just different constructions. As a radial, the 520/85R42 will carry 12% to 19% more load at the same inflation pressure than the bias tire. Table 1 compares the per-tire load carrying capacity of a bias 20.8-42 to the radial 520/85R42 (20.8R42) at common inflation pressures. Figure 2 compares the load tables at all the base inflation pressures.

The 12% to 19% increase in load capacity doesn't seem like much, but when these two tires are placed on a mechanical front wheel drive tractor with a PTO output of 198 kW and pulling a 16-row front fold corn planter, the inflation pressure increases could be considered significant. In the spring of 2016, a Case IH Magnum 310 tractor with a 16-row Case IH 1255 corn planter was weighed by Bridgestone Americas' Tire Operation. The tractor rear axle weight with the planter in transport position without any seed or fertilizer was 12,610 kg (Figure 3). Using a single tire configuration on the rear axle of the tractor, each rear tire would need to carry 6,305 kg. The load and inflation table shows neither the 20.8-42 nor the 520/85R42 in a single tire configuration would have enough load capacity

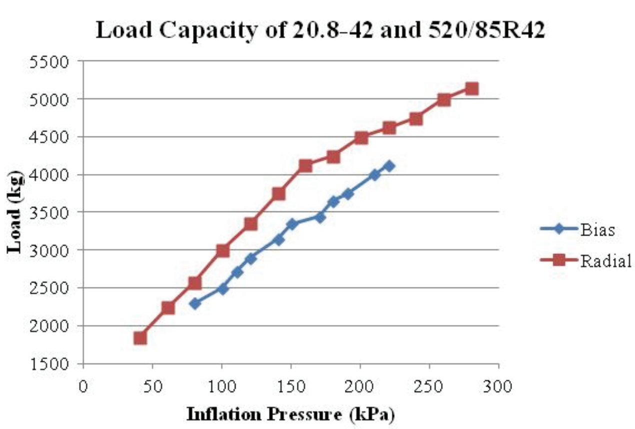

Figure 2. Graphical view of load table for 20.8-42 and 520/85R42 tires (from Tire and Rim Association, Inc., 2016 Year Book).

Figure 3. Case IH Magnum 310 tractor with 16 row Case IH 1255 planter being weighed in spring 2016.

to carry the axle load. In regions where equipment is not limited by vehicle width, duals can be added to carry the axle weight. When used as duals, each tire would carry 3152.5 kg; the 20.8-42 would require 180 kPa, and the 520/85R42 would require 130 kPa. The dual configuration allows the inflation pressure to decrease 28% and applies less contact pressure onto the soil. This is one reason the radial tires have replaced bias tires on newer equipment, but what happens when duals cannot be used?

In countries where there are laws that restrict equipment widths that travel on public roads, users have to determine another solution. In this example, the Case IH 310 tractor can be fitted with 710/70R42 as singles on the rear axle. The 710/70R42 tire is taller and wider than the 520/85R42 and, when used as a single, are narrow enough to drive on public roads, while dual 580/85R42 tires are not. To carry the axle load of 12,610 kg, a minimum inflation pressure of 240 kPa is required in the 710/70R42. The 710/70R42 used as a single can carry the axle weight, but the required inflation pressure is 84% higher than the customer is allowed to use in the dual 520/85R42 tires. This increased inflation pressure will increase the soil contact pressures. By limiting tractor width, users have limited solutions available to them, and limiting tractor width can cause higher levels of soil compaction. To help users meet the width restriction and reduce inflation pressures, the tire industry had to develop new standards.

New Load/Inflation Pressure Standards

To address customer concerns of increased inflation pressure on radial tires, tire manufacturers developed new standards that would allow a radial tire to operate at higher deflections. The new standards are IF, VF, and IF/CFO (Cyclic Field Operation). These standards modify the radial tire load/inflation pressure formula to carry higher loads at a standard pressure rating. The formula used to calculate the load capacity of a radial tire at a specific inflation pressure is:

$$L = (P + PO) \times K1 \times K \times 10^{-5} \times V^{2/3} \qquad (1)$$

where L = load (kg)
P = inflation pressure (kPa)
PO = pressure constant (60 kPa)
K = load Factor
V = volume calculation (mm^3)
K1 = radial tire formula constant
The formula uses the same constants when calculating the load between the standard radial, IF, and VF tires except the K1 value.

Definition of Standard

A radial tire marked IF (Increased Flexion) is designed to carry 20% more load at the same inflation pressure as a standard radial tire. In the load formula, a standard tire uses a K1 factor of 1, and an IF tire uses a K1 value of 1.2. The 1.2 K1 increase changes the deflection of the tire in operation. A standard radial agricultural tire will deflect 18% to 22% at the proper load and inflation pressure. In contrast, an IF marked radial tire will deflect 24% to 26%.

A radial tire marked VF (Very High Flexion) is designed to carry 40% more load at the same inflation pressure as a standard radial tire. In the load formula, a VF tire will use a K1 value of 1.4. The deflection of a VF tire increases over a standard radial and will operate in a deflection of 28% to 31%.

The higher deflections allow the tires to carry the same axle loads at lower inflation pressures. In the example of the Case IH Magnum 310 tractor, when an IF 710/70R42 is used in place of the standard 710/70R42, the inflation pressure required to carry the axle weight of 12,610 kg is reduced from 240 kPa to 150 kPa. In this application the inflation pressure of the IF 710/70R42 is only 15% higher than the dual 520/85R42. If the user used a VF710/70R42 in place of the standard 710/70R42, the inflation pressure required to carry the axle load of 12,610 kg is reduced from 240 kPa to 120 kPa. In this application the inflation pressure of the VF710/70R42 single tire is 8% less than the dual 520/85R42 tires.

Table 2. Sensor used in field testing.

Sensor Information	
Brand	Tekscan
Model	7101 (3 Sensors)
Sensor Size	≈ 60 in. x 20 in.
Sensor Setup	Calibrated at 50 psi increments

Measuring Soil Contact Pressure

To measure the effect to soil between standard, IF and VF inflation pressure, Bridgestone Americas Tire Operation developed a test to measure the contact pressures of tires as they are driven on soil. A similar test was previously used by Rethmel and Harris (2013) and by Rethmel (2013).

The measurement technique used in this project is based on the idea of measuring subsurface pressure beneath agricultural equipment in actual service conditions. The overall equipment setup is a pressure-sensing mat placed on a solid surface and then covered with a soil medium. Agricultural equipment can then be driven on the soil medium while the pressure sensed by the mat is recorded.

Various trials were conducted with sensors of different sizes, resolutions and calibration values to determine an acceptable sensor. A pressure-sensing mat produced by Tekscan, Inc. (South Boston, MA) (Table 2) was used in the final stages of testing. The sensor is able to record pressure as sensed by the individual pixels on the mat and display it in a color graphic. The graphic displays areas of higher pressure with a red color and areas of lower pressure with a blue color. The images can be scaled to various limitations (Figure 4).

The sensor output can be a single static image representing a moment in time, or the sensor can be set in record mode to capture images at a fixed rate over a period of time. The recorded images can be shown as a video or as a composite image of the recording over time. The composite image is created by displaying the highest value sensed by each pixel over the length of the recording.

Test Layout

A pit was constructed for the testing (Figures 5 and 6). An area 40 feet long by 6 feet wide and 2 feet deep was filled with sand level with the surrounding field. The sensor

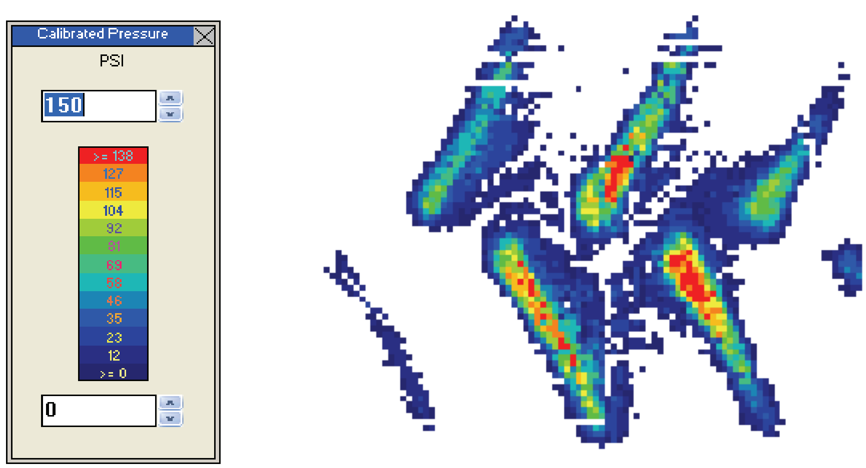

Figure 4. Static pressure image of an R-1W agricultural drive tire, shown with pressure scale.

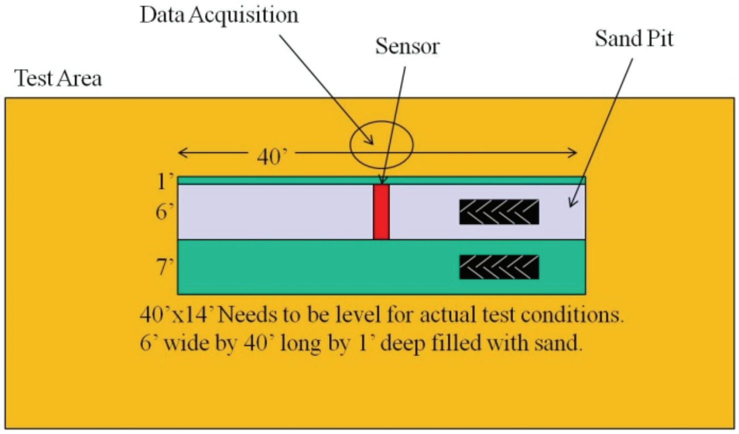

Figure 5. Top view showing sand pit layout.

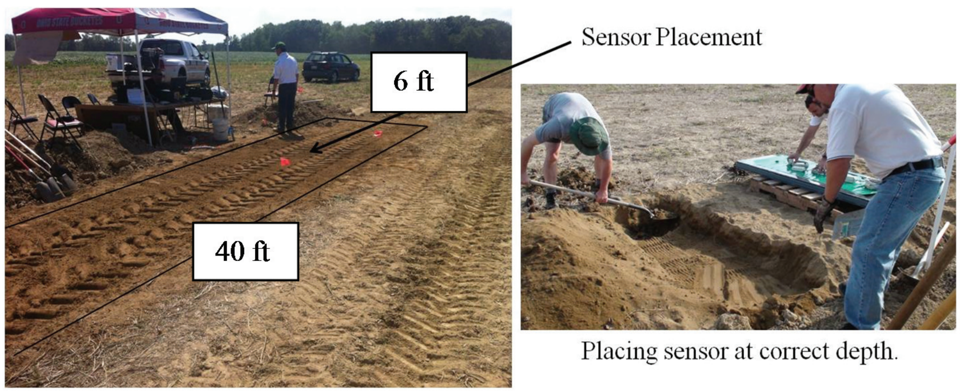

Figure 6. Sand pit and sensor placement.

was placed in the center of the pit so the tractors could be driven over the sensor. One side of the tractor being tested would travel over the sensor, and the other side of the tractor would be supported by the field adjacent to the sensor. Testing could be completed traveling in either direction.

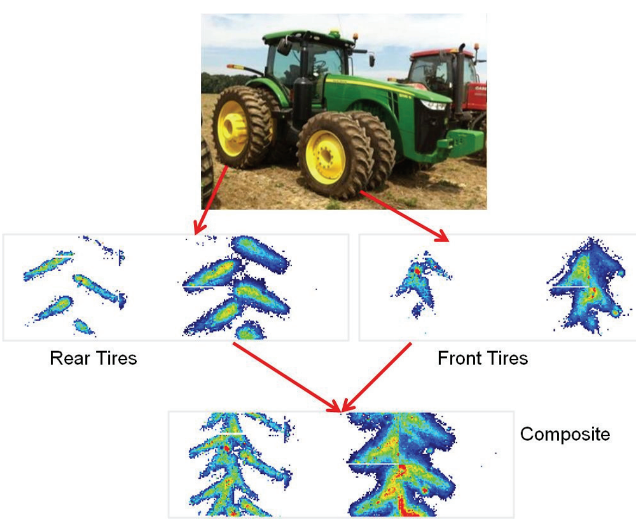

Figure 7. Composite pressure image creation.

Field Testing

With the use of moving equipment, it was necessary to make a recording of the pressure sensed by the equipment as the equipment was driven over the buried sensor. The recording was then post-processed to display one image that shows the maximum pressure sensed by each pixel on the sensor over the course of the video. This allows for a total impact from the equipment to be visualized. The contributions from both the front and rear tires can be seen as one image (Figure 7).

Test Procedure

Testing was completed with the sensor buried in sand and allowed for 3 or 4 inches of sand to cover the top of the sensor. The tractors were driven across the sensor first in one direction and then in the reverse direction. A pressure recording was created during the length of the run. The recording was created for both the left side of the tractor and then the right side of the tractor. After each run the sand over the sensor was raked up and returned to the original uncompacted state. Testing was completed with ≈0% wheel slip, as no drawbar load was applied to the tractor. The test tractors were a John Deere 8335R MFWD with dual 420/85R34 tires on the front axle and dual 480/80R50 tires on the rear axle and a Case IH Steiger 500 4WD with dual 710/70R42 tires on the front and rear axles (Figure 8).

Figure 8. Test tractors.

Test Results

The recordings were analyzed to determine the pressure values recorded by the sensor. The results of the individual runs are displayed as composite images in Figures 9 and 10. A count of the pixels at various pressure readings is shown in Table 3 with 3-inch sand depth for the John Deere 8335R and Table 4 with 4-inch sand depth for the Case IH Steiger 500.

The peak pressure sensed by any pixel in the sensor was recorded. Following testing, the data were analyzed, and it was determined that the peak value is related to pebbles, stones, or other debris on the sensor (Figure 11). The peak pressure locations are isolated points on the sensor that do not represent true peaks as caused by a tire. It was determined that the peak pressure should not be used to make judgments about soil compaction.

Test Conditions					
Tractor		8335R		8335R	
Inflation Pressure Standard		Standard - Radial		IF - Radial	
Tire Position		Front	Rear	Front	Rear
Axle Weight (lbs)	All Runs	15,500	20,400	15,500	20,400
Tire Inflation (psi)	All Runs	16	14	11	10.25
		Soil Depth (in.)	Wheel Slip (%)	Soil Depth (in.)	Wheel Slip (%)
Soil Depth (in.) & Wheel Slip (%)	All Runs	3	0	3	0
Average Pressure (psi)	Average	14.7		12.8	
	Minimum	13.0		12.0	
	Maximum	17.0		14.0	
	Standard Deviation	1.4		1.0	

Composite

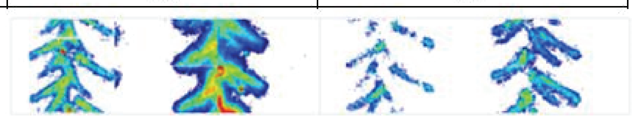

Figure 9. Summary of soil contact pressures from standard radial and IF tires on a John Deere 8335R MFWD tractor.

Tractor	Case IH Steiger 500		Case IH Steiger 500		Case IH Steiger 500	
Operating Condition	Over-Inflated		Standard		IF	
Tire Position	Rear		Rear		Rear	
Tire Inflation (psi)	15		10		6	
	Soil Depth (in.)	Wheel Slip (%)	Soil Depth (in.)	Wheel Slip (%)	Soil Depth (in.)	Wheel Slip (%)
Soil Depth (in.) & Wheel Slip (%)	4	0	4	0	4	0

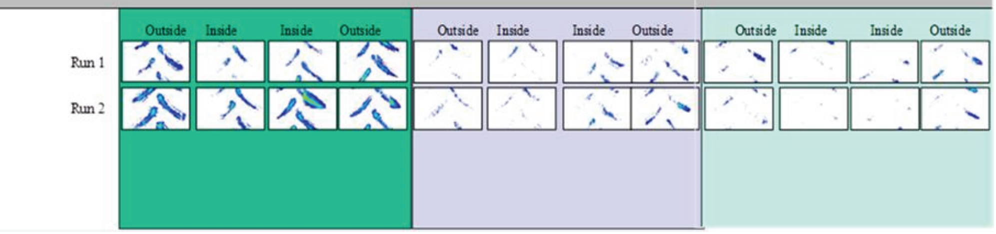

Figure 10. Summary of soil contact pressures from standard radial and IF tires on a Case IH Steiger 500 tractor.

Table 3. Pixel analysis for John Deere 8335R tractor with 3 in. sensor depth. The column labelled Bin (psi) is the pressure range the sensor was recording. The column labelled Frequency is the number of pixels recorded in the pressure range found in column Bin (psi).

Standard Tires - Run 1		Standard Tires - Run 2		Standard Tires - Run 3		Standard Tires - Run 4		Standard Tires - Run 5		Standard Tires - Run 6	
Bin (psi)	*Frequency*	*Bin (psi)*	*Frequency*	*Bin (psi)*	*Frequency*	*Bin (psi)*	*Frequency*	*Bin (psi)*	*Frequency*	*Bin (psi)*	*Frequency*
0	15992	0	15982	0	17037	0	19596	0	19136	0	20060
0.01 -2.0	64	0.01 -2.0	123	0.01 -2.0	90	0.01 -2.0	56	0.01 -2.0	62	0.01 -2.0	61
2.01-4.0	738	2.01-4.0	1037	2.01-4.0	904	2.01-4.0	529	2.01-4.0	512	2.01-4.0	518
4.01-6.0	992	4.01-6.0	1317	4.01-6.0	1215	4.01-6.0	747	4.01-6.0	739	4.01-6.0	682
6.01-8.0	640	6.01-8.0	900	6.01-8.0	782	6.01-8.0	451	6.01-8.0	484	6.01-8.0	436
8.01-10.0	715	8.01-10.0	986	8.01-10.0	776	8.01-10.0	565	8.01-10.0	548	8.01-10.0	502
10.01-15.0	1635	10.01-15.0	2070	10.01-15.0	1633	10.01-15.0	1126	10.01-15.0	1393	10.01-15.0	1183
15.01-20.0	1369	15.01-20.0	1252	15.01-20.0	1251	15.01-20.0	843	15.01-20.0	912	15.01-20.0	718
20.01-30.0	1960	20.01-30.0	1134	20.01-30.0	1285	20.01-30.0	961	20.01-30.0	1118	20.01-30.0	783
30.0 +	1239	30.0 +	543	30.0 +	371	30.0 +	470	30.0 +	440	30.0 +	401

IF Tires - Run 1		IF Tires - Run 2		IF Tires - Run 3		IF Tires - Run 4	
Bin (psi)	*Frequency*	*Bin (psi)*	*Frequency*	*Bin (psi)*	*Frequency*	*Bin (psi)*	*Frequency*
0	20865	0	20852	0	20597	0	21294
0.01 -2.0	52	0.01 -2.0	53	0.01 -2.0	57	0.01 -2.0	54
2.01-4.0	481	2.01-4.0	520	2.01-4.0	467	2.01-4.0	441
4.01-6.0	731	4.01-6.0	696	4.01-6.0	681	4.01-6.0	656
6.01-8.0	494	6.01-8.0	456	6.01-8.0	453	6.01-8.0	428
8.01-10.0	542	8.01-10.0	505	8.01-10.0	505	8.01-10.0	476
10.01-15.0	1042	10.01-15.0	1013	10.01-15.0	1114	10.01-15.0	898
15.01-20.0	549	15.01-20.0	588	15.01-20.0	628	15.01-20.0	473
20.01-30.0	448	20.01-30.0	499	20.01-30.0	558	20.01-30.0	434
30.0 +	140	30.0 +	162	30.0 +	284	30.0 +	190

Table 4. Pixel analysis for Case IH Steiger 500 4wd tractor with 4 inch sensor depth. The column labelled Bin (psi) is the pressure range the sensor was recording. The column labelled Frequency is the number of pixels recorded in the pressure range found in column Bin (psi).

Over-Inflated Tires		Over-Inflated Tires		Standard Tires		Standard Tires		IF Tires		IF Tires	
Run 1 (15 psi)		Run 2 (15 psi)		Run 1 (10 psi)		Run 2 (10 psi)		Run 1 (6 psi)		Run 2 (6 psi)	
Bin (psi)	***Frequency***	***Bin (psi)***	***Frequency***	***Bin (psi)***	***Frequency***	***Bin (psi)***	***Frequency***	***Bin (psi)***	***Frequency***	***Bin (psi)***	***Frequency***
0	96952	0	93416	0	100126	0	99825	0	100291	0	100651
0.01 -2.0	61	0.01 -2.0	38	0.01 -2.0	17	0.01 -2.0	11	0.01 -2.0	44	0.01 -2.0	15
2.01-4.0	832	2.01-4.0	1119	2.01-4.0	346	2.01-4.0	382	2.01-4.0	285	2.01-4.0	159
4.01-6.0	942	4.01-6.0	1295	4.01-6.0	328	4.01-6.0	388	4.01-6.0	280	4.01-6.0	179
6.01-8.0	637	6.01-8.0	1062	6.01-8.0	178	6.01-8.0	254	6.01-8.0	172	6.01-8.0	105
8.01-10.0	467	8.01-10.0	924	8.01-10.0	150	8.01-10.0	148	8.01-10.0	99	8.01-10.0	65
10.01-15.0	790	10.01-15.0	1693	10.01-15.0	145	10.01-15.0	229	10.01-15.0	142	10.01-15.0	109
15.01-20.0	353	15.01-20.0	955	15.01-20.0	50	15.01-20.0	79	15.01-20.0	35	15.01-20.0	58
20.01-30.0	270	20.01-30.0	728	20.01-30.0	31	20.01-30.0	48	20.01-30.0	23	20.01-30.0	29
30.0 +	72	30.0 +	146	30.0 +	5	30.0 +	12	30.0 +	5	30.0 +	6

3-inch Depth Test Results for John Deere 8335R Tractor

The first four runs of the data were analyzed to determine the pixel count for each test set up. The inflation pressure was set based on the axle weight of the tractor. The inflation pressures for the standard radial tire was 16 psi in the front 420/84R34 tires and 14 psi in the rear 480/80R50 tires. The inflation pressures for the IF radial tire was 11 psi in the front IF 420/84R34 tires and 10.25 psi in the rear IF 480/80R50 tires. Figure 9 lays out the axle load, inflation pressure and average pressure recorded in the test. The data from the 3-inch sand depth were analyzed; and the IF tires registered 4953 pixels having pressures greater than 15 psi, while the standard tires had 12678 pixels above 15 psi.

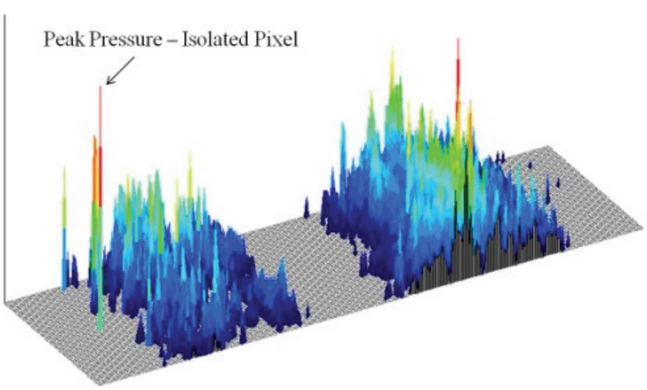

Figure 11. Peak pressure example.

Figure 9 is a summary of the pressure used on the John Deere 8335R MFWD tractor, and the composite picture of the contact pressure is below each pressure treatment. As the tire inflation pressure is decreased from standard to IF pressure, the contact pressure is decreased, and that is shown by the reduction of red and orange colors in the image.

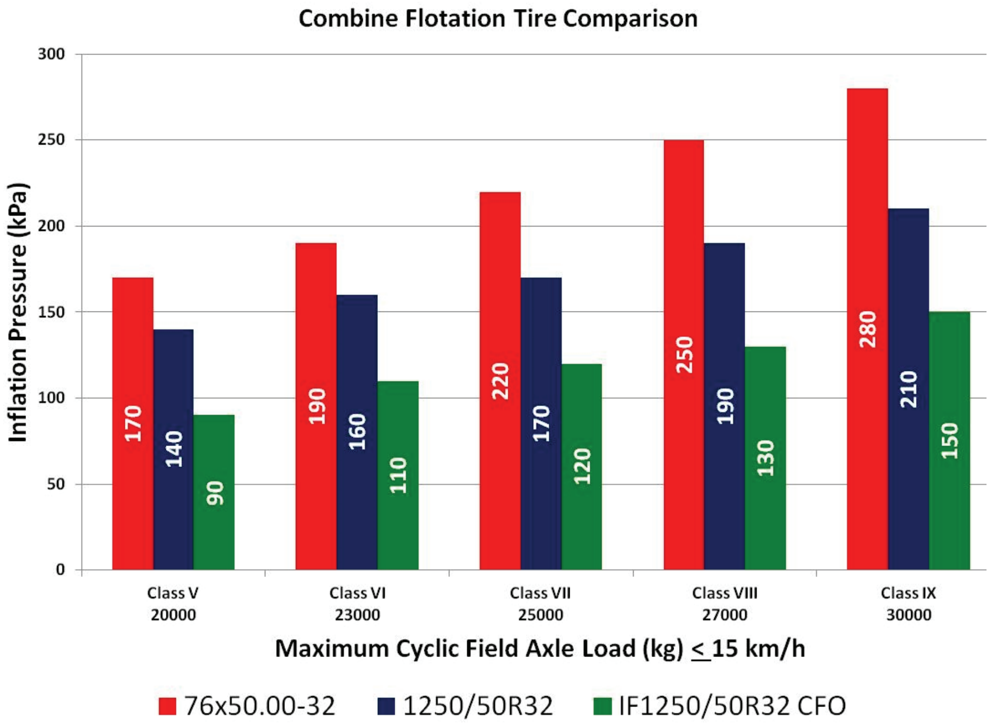

Figure 12. Inflation pressure needed to carry harvester drive axle loads.

4-inch Depth Test Results for Case IH Steiger 500

When evaluating the Case IH Steiger 500, the rear axle was used to develop the contact pressure analysis. The rear axle weighed 24,000 lbs. The tire inflation pressures were set at 15 psi (over-inflated), 10 psi (standard pressure), and 6 psi (IF pressure). The IF pressure registered an average of 78 pixels (3.12 in.^{2}) with pressure greater than 15 psi, the standard pressure registered 113 pixels (4.52 in.^{2}) above 15 psi, and the over-inflated pressure registered 1262 pixels (50.48 in.^{2}) with a pressure reading greater than 15 psi.

Figure 10 is a summary of the tire inflation pressures used on the Case IH Steiger 500 4wd tractor, and the composite picture of the contact pressure is beneath each inflation pressure treatment on the rear axle of the tractor that weighs 24,000 pounds. As the inflation pressure is decreased from over-inflated (15 psi) to standard (10 psi) to IF (6 psi) pressure, the contact pressure is decreased; and that is shown by the reduction of red and orange colors in the image. When the inflation pressures are reduced to the IF condition, the sensor is having a hard time reading any contact pressures at the 4-inch depth.

Applications

The IF/VF standard has allowed users to manage inflation pressures on tractors, but the industry is moving forward by expanding the reach. On high clearance sprayers with tank capacities of 3800 L and larger, original equipment manufacturers are using IF/VF tires when users are requesting tires with sections widths of 420 mm or less. This is the first major equipment segment that moved to the IF/VF tires to reduce inflation pressure of 600+ kPa down to 440 kPa. While the inflation pressure difference may not seem like much, it is a step in the correct direction.

The next progression of IF/VF technology will be in the harvesting sector. Manufacturers are developing Class IX combines, and standard radial tires are requiring up to 360 kPa. To address this need the tire industry has developed the IF/CFO (Cyclic Field Operation) standard. This standard allows a tire marked IF/CFO to carry 55% extra load when used at speeds less than 15 km/h on equipment like combines and grain carts that are loaded and then carry weight for distances less than one mile. Figure 12 is an illustration on the inflation pressure required to carry the axle load typically experienced on various classes of combines. The x-axis is the typical axle load (kg) of various classes of combines, and the y-axis is the inflation pressure to carry the axle load. There are three tires listed: a 76x50.00-32 Bias flotation tire, a standard 1250/50R32 Radial, and an IF 1250/50R32 CFO Radial. With the new IF/CFO standard, the IF1250/50R32 CFO will carry the axle load of a Class IX combine at the inflation pressure of the 76x50.00-32 on a Class V combine. These IF/CFO tires are also approved for use on grain carts.

Conclusion

As agricultural equipment gets larger and heavier, users need to determine if there is an economical benefit of using the IF, VF, or IF/CFO tires. The soil contact pressure study conducted by Bridgestone Americas Tire Operation confirmed the contact pressure measured at 3- and 4-inch depths can be correlated to tire inflation pressure. These new tire technologies allow users to use lower inflation pressures compared to standard radials, to help reduce the contact pressure exerted on the soil, thereby reducing compaction. In some applications, such as high-clearance sprayers and grain carts, the IF, VF, and IF/CFO tires are required to carry the axle loads of these heavy vehicles. On tractors and combines the IF, VF, and IF/CFO tires allow users to reduce inflation pressures to minimize soil compaction. At this time there are limited data available on how these new technologies will impact a user's final crop yield, but multi-year studies are being conducted.

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