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Effect of Inflation Pressure on the Self-Cleaning Performance of Different Radial Agricultural Tires

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Abstract

Self-cleaning is an important characteristic of agricultural tires because it can affect tire–soil interaction and traction under wet soil conditions. However, studies quantifying the effects of tire tread design and inflation pressure on this process remain limited. The objective of this study was to evaluate the distance traveled under field capacity soil conditions and the self-cleaning performance of four radial agricultural tires subjected to three inflation pressures. The experiments were conducted at the Federal University of Mato Grosso under controlled soil moisture conditions. A New Holland T7.205 tractor equipped with a four-disc plow was used to apply load and promote tire saturation with wet soil. The evaluated variables were the distance traveled until tread saturation and the number of tire revolutions required for soil removal. The lowest inflation pressure (1.2 bar) resulted in the greatest distance traveled before tread saturation, whereas higher inflation pressures generally reduced the distance traveled before saturation. Tire P exhibited the best results in terms of the greatest distance traveled before soil saturation in the tread at inflation pressures of 1.2, 1.6 and 2.0 bar. At an inflation pressure of 1.2 bar, tire M required the lowest number of tire revolutions for soil removal from the tread, averaging 9 revolutions. At 2.0 bar, tires P and F required fewer tire revolutions for soil removal than tires G and M, averaging 18 and 19 revolutions, respectively.

Keywords: soil–machine interaction; agricultural mechanization; plow

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Academic Editor: Eugenio Cavallo

Received: 5 September 2026
Revised: 24 September 2026
Accepted: 29 September 2026
Published: 3 October 2026

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1. Introduction

Agricultural mechanization has become increasingly dependent on optimizing tire–soil interaction to maximize operational efficiency while minimizing energy consumption and soil degradation [1–3]. Agricultural tires constitute the primary interface between the tractor and the soil, directly influencing drawbar pull, traction efficiency, wheel slip, fuel consumption, field capacity, and soil compaction [4–7]. Consequently, tire performance plays a decisive role in converting engine power into useful tractive effort and, ultimately, in the productivity and sustainability of agricultural operations [8–10].

Among the various performance characteristics of agricultural tires, self-cleaning capacity is particularly important under wet soil conditions. Self-cleaning refers to the tire's ability to remove soil adhering between the tread lugs during rotation, thereby preserving the original tread geometry and maintaining efficient tire–soil interaction [8,9]. When the tread voids become filled with soil, the effective height of the tread lugs is reduced, limiting

their penetration into the soil and decreasing the development of the shear stresses required for traction generation [4,10]. As a result, wheel slip increases, drawbar pull decreases, and the tractor's operational efficiency is reduced [6,10].

The self-cleaning process depends on the combined effects of soil properties, tire design, and operating conditions. Soil texture, moisture content, clay content, bulk density, cohesion, adhesion, and plasticity influence both the adhesion of soil particles to the tire surface and the ease with which adhered soil is released during tire rotation [11–13]. Cohesive soils with high clay content generally exhibit greater adhesion to rubber surfaces, promoting tread clogging and reducing traction efficiency, particularly when soil moisture approaches field capacity [12,13].

Tire geometry is another key factor controlling self-cleaning performance. Characteristics such as tread lug height, lug angle, lug width, lug spacing, tread depth, shoulder configuration, and overall tread pattern influence both soil penetration and soil release during operation [1,9,14]. Greater lug spacing increases the available void volume for soil release, facilitating soil ejection and delaying tread saturation under wet conditions. Conversely, reduced lug spacing promotes rapid clogging of the tread voids, decreasing the effectiveness of the mechanical interlocking between the tire and the soil responsible for traction generation [9,14]. Although taller tread lugs generally improve traction by increasing soil penetration, they may also retain greater amounts of soil if the tread geometry does not adequately promote self-cleaning [14].

In radial agricultural tires, carcass flexibility provides an additional self-cleaning mechanism. During each tire revolution, cyclic carcass deformation and elastic recovery modify the stress distribution acting on the adhered soil, promoting crack initiation and the detachment of soil aggregates from the tread surface [8,9]. Compared with bias-ply tires, radial tires generally exhibit greater sidewall flexibility and a larger contact area, characteristics that influence both stress transmission to the soil and the tire's ability to remove adhered soil during operation [8,15].

Operating conditions also exert a significant influence on self-cleaning behavior. Inflation pressure modifies the tire footprint, ground pressure distribution, tread lug penetration, and carcass deformation [8,11,15]. Lower inflation pressures generally increase the contact area and carcass deformation, enhancing the cyclic deformation responsible for soil detachment. In contrast, higher inflation pressures reduce tire flexibility, limit tread deformation, and may accelerate tread clogging under saturated soil conditions [8,15]. Tire load, forward speed, wheel slip, and soil moisture interact with inflation pressure, making self-cleaning a dynamic process controlled simultaneously by multiple variables [9,13,16].

From a terramechanics perspective, self-cleaning directly influences the development of shear stresses at the tire–soil interface. Classical traction theory states that maximum tractive effort is achieved when the tread lugs maintain direct contact with undisturbed soil capable of resisting shear deformation [4,6,10]. Soil accumulation within the tread voids reduces the effective lug geometry, weakens the mechanical interlocking between the tire and the soil, and decreases the available shear strength for traction development. Consequently, poor self-cleaning performance not only reduces tractive efficiency but also increases wheel slip, fuel consumption, rolling resistance, and the likelihood of greater soil compaction resulting from repeated tire passes [10,17].

Despite the practical importance of self-cleaning under wet soil conditions, the effects of inflation pressure on the soil accumulation and subsequent removal from the tread of different radial agricultural tire models remain insufficiently characterized. In particular, there is limited experimental information on how different tire constructions respond to changes in inflation pressure when evaluated using quantitative indicators of tread soil

accumulation and removal. This knowledge gap limits the understanding of the interaction between inflation pressure and tire tread characteristics during the self-cleaning process.

Therefore, the objective of this study was to evaluate the distance traveled under field capacity soil conditions and the self-cleaning behavior of different radial agricultural tire models subjected to different inflation pressures.

2. Materials and Methods

The experiments were conducted at the experimental area of the Federal University of Mato Grosso (UFMT), Sinop campus, Mato Grosso State, Brazil. The soil was previously prepared by subsoiling to a depth of 0.40 m, followed by two passes of a leveling harrow to ensure adequate soil fragmentation. The experimental area was characterized by a clayey soil texture, consisting of 57% clay, 19% silt, and 24% sand. Prior to testing, the area was irrigated using a sprinkler system until field capacity was reached, resulting in a soil water content of 30% on a gravimetric basis. This condition was established to promote soil adhesion to the tires and enable the evaluation of the self-cleaning process.

The methodology used to evaluate tire self-cleaning was based on internal procedures developed by Prometeon/Pirelli and Trelleborg for agricultural tire performance testing under high soil moisture conditions. Currently, there is no standardized technical protocol for this type of test.

Therefore, an operational definition of tire self-cleaning performance was established for this study based on two measurable and reproducible indicators. Tire self-cleaning performance was defined as the ability of the tire tread to resist soil accumulation between the lugs and subsequently remove the adhered soil during tire rotation. Two complementary indicators were used to quantitatively characterize this behavior: (i) the distance traveled until tread saturation with soil (m), and (ii) the number of tire revolutions required to remove the adhered soil until a residual soil level of 10% was reached. The distance traveled until tread saturation represents the tire's resistance to soil accumulation, whereas the number of tire revolutions represents its ability to remove the soil accumulated between the tread lugs after saturation. Therefore, greater distances until saturation and fewer tire revolutions required to reach the 10% residual soil level indicate better self-cleaning performance under the evaluated conditions.

An agricultural tractor New Holland T7.205, with a rated power of 182 hp, was used in the experiments. The tractor was equipped with 420/85R24 tires on the front axle and dual 520/85R38 tires on the rear axle. The total ballast used consisted exclusively of metal ballast, with 990 kg positioned on the front axle and 650 kg on the rear axle. The total tractor mass, including the metal ballast, was 8850 kg, with 46% (4096 kg) distributed on the front axle and 54% (4754 kg) on the rear axle. No liquid ballast was used in the tires. A four-disc KLR plow, equipped with 32-inch discs, was attached to the tractor's three-point hydraulic hitch system. During the tests, the tractor operated with the differential lock engaged and the front-wheel assist (FWA) disengaged to standardize the traction conditions among treatments.

The experimental procedure consisted of driving the tractor over soil at field capacity, with the plow lowered to the working position at a depth of 0.30 m, requiring an approximately 2000 kgf horizontal force to pull the plow (Figure 1a).

The tractor was operated at a speed of 7 km h^{-1} until the tire tread reached the soil saturation condition, characterized by the complete filling of the tread voids with adhered soil.



(a) **(b)**

Figure 1. (**a**) Beginning of the evaluation; (**b**) end of the evaluation, showing the distance traveled until complete filling of the tire tread with soil.

Tread saturation was operationally identified when the tread voids were completely filled with adhered soil and the tractor was no longer able to move forward, remaining stationary at the same position due to excessive tire slip.

This condition was identified when the tractor was no longer able to move forward and remained stationary at the same position due to excessive tire slip.

At this point, the operator recorded the occurrence using a program developed at UFMT in the MATLAB version: 24.2.0.2740171 (R2024b) programming environment. Simultaneously, the pulses generated by an encoder with a resolution of 60 pulses per revolution were recorded and used to determine the number of tire revolutions (Figure 1b).

After the complete filling of the spaces between the tire lugs with soil and the consequent loss of the tractor's ability to move, the plow was raised, removing the additional load applied to the tractor (Figure 2a). Subsequently, the tractor was driven in reverse over a firm and dry surface at a speed of 7 km h^{-1}, and the number of tire revolutions required to promote the detachment and removal of the soil adhered to the tire tread was recorded. Tire self-cleaning was considered complete when the amount of soil remaining between the lugs was reduced to 10% of the initial soil adhered under the saturated condition (Figure 2b).



(a) **(b)**

Figure 2. (**a**) Beginning of the evaluation; (**b**) end of the evaluation, showing the number of tire revolutions required to unload the tread.

The amount of residual soil was measured using three optical sensors (Leuze, model ODS 96B). The sensors were installed below the tractor's rear fender, above the inner right rear tire of the dual-tire assembly. Data were collected at a frequency of 1 Hz. The measurements obtained before and after the self-cleaning process were compared using a program developed at UFMT, with the data synchronized with the distance traveled.

The encoder pulses were used to determine the number of tire revolutions required to complete the tire self-cleaning process.

The experiment was conducted using a randomized complete block design with four replications in a 4 × 3 factorial arrangement, consisting of four radial agricultural tire models and three inflation pressures. Each experimental plot measured 30 m in length and 6 m in width.

The tire models evaluated were: (P) Prometeon/Pirelli PHP, size 520/85R38, with R1W lugs; (F) Firestone Traction, size 520/85R38, with R1 lugs; (M) Michelin Agribib, size 520/85R38, with R1W lugs; and (G) Goodyear APR, size 520/85R38, with R1 lugs. The inflation pressures evaluated were 1.2, 1.6, and 2.0 bar. The nominal inflation pressure of 1.6 bar was adopted as the reference condition. Based on this value, one pressure below the nominal pressure (1.2 bar) and one pressure above the nominal pressure (2.0 bar) were selected to evaluate tire behavior under different inflation conditions, representing a range of load demands that may occur during field operations.

During each test, the GNSS system independently measured the actual distance traveled by the tractor, providing the displacement data used to determine the distance traveled until tread saturation. Simultaneously, an incremental encoder installed on the evaluated tire generated 60 pulses for each complete tire revolution. The encoder pulses were continuously recorded by the data acquisition system and converted into the corresponding number of tire revolutions. Thus, the GNSS and encoder provided independent measurements: GNSS was used to determine the distance traveled by the tractor, whereas the encoder was used to determine the rotational displacement of the tire. The dynamic rolling radius was subsequently calculated from the relationship between the distance traveled measured by GNSS and the total angular displacement of the tire obtained from the encoder. Four repetitions were performed for each tire model and inflation pressure.

The analyzed variables were the distance traveled until tread saturation with wet soil and the number of tire revolutions required for soil removal of the adhered soil. The data were subjected to analysis of variance (ANOVA) using the F-test. The assumptions of normality and homogeneity of variances were assessed using the Shapiro–Wilk and Levene tests, respectively. When necessary, the data were log-transformed prior to analysis of variance to meet these assumptions. When significant treatment effects were detected, means were compared using Tukey's test at the 5% probability level. All statistical analyses were performed using Sisvar software version 6.6.

3. Results and Discussion

Prior to the analysis of variance, the assumptions of normality and homogeneity of variances were assessed. After log transformation, the residuals met the assumptions required for ANOVA for both response variables. For distance traveled (Table 1), the Shapiro–Wilk and Levene tests yielded W = 0.9787 (p = 0.5247) and F = 0.1992 (p = 0.9966), respectively. For the number of tire revolutions (Table 3), the corresponding values were W = 0.9761 (p = 0.4294) and F = 0.3899 (p = 0.9514), respectively. Thus, the transformed data were considered suitable for subsequent analysis of variance. The analysis of variance revealed significant effects of inflation pressure, tire model, and the interaction between these factors on the distance traveled until soil accumulation occurred on the tire tread (Table 1). Inflation pressure presented the highest F-value, followed by tire model, indicating that

inflation pressure was the factor that most strongly influenced the distance traveled until soil accumulation occurred on the evaluated tires. This result highlights the importance of properly adjusting inflation pressure to optimize tire–soil interaction and the mechanisms associated with the detachment of soil adhered to the tire tread.

Table 1. Summary of the analysis of variance for the variable distance traveled until soil accumulation on agricultural tires as a function of inflation pressure and tire model.

Source of Variation	DF	F-Value	*p*-Value
Blocks	3	317.04	<0.0001
Inflation Pressure	2	1887.78	<0.0001
Tire Model	3	683.20	<0.0001
Inflation Pressure × Tire Model	6	31.88	<0.0001
Residual	33	–	–
CV (%)	–	2.15	–

Note: Data were log-transformed prior to analysis to meet the assumptions of normality and homogeneity of variances. The coefficient of variation (CV) was calculated based on the residual mean square of the transformed data.

The significant interaction between inflation pressure and tire model indicates that the response of the different tire models varied according to the inflation pressure applied, justifying the analysis of simple effects and the comparison of treatment means (Table 2).

Table 2. Interaction between inflation pressure and different radial tire types for the distance traveled until soil saturation of the tires.

	Tire Model			
Inflation Pressure (bar)	**F**	**G**	**M**	**P**
1.2	8.00 ± 0.73 cA	11.00 ± 1.18 bA	12.00 ± 1.07 bA	19.00 ± 1.66 aA
1.6	5.00 ± 0.54 bB	5.50 ± 0.62 bB	5.00 ± 0.55 bB	9.00 ± 0.94 aB
2.0	4.50 ± 0.46 bB	4.50 ± 0.43 bB	4.00 ± 0.55 bB	8.50 ± 0.92 aB

Values are presented as mean ± standard error (SE). Means followed by the same lowercase letter within a row and the same uppercase letter within a column do not differ significantly according to Tukey's test at the 5% probability level.

It was observed that an inflation pressure of 1.2 bar provided the greatest travel distances for all evaluated tires, with mean values ranging from 8.0 to 19.0 m. In contrast, inflation pressures of 1.6 and 2.0 bar resulted in substantial reductions in this variable, indicating that increasing inflation pressure impairs the self-cleaning capacity of agricultural tires (Table 2). Similar responses have recently been reported in studies evaluating the influence of inflation pressure on tire–soil interaction, contact stress distribution, and traction efficiency under different soil conditions [18–20].

Among the evaluated tire models, tire P exhibited the greatest travel distances before tread saturation at all tested inflation pressures. At 1.2 bar, tire P achieved a mean travel distance of 19.0 m, which was significantly greater than those observed for the other tire models. Tires G and M exhibited intermediate values, whereas tire F showed the lowest mean travel distance.

The geometric characteristics of the tread may have contributed to the differences observed among the tire models. However, other structural characteristics of the tires were not directly evaluated in the present study and, therefore, cannot be used to establish causal relationships. According to Dohrman [14], tread geometry influences self-cleaning behavior because it affects the tire's ability to retain and release soil particles during rotation. Recent studies using numerical simulations and finite element analyses have also demonstrated

that tread geometry can influence contact pressure, shear stress development, soil removal mechanisms, and tire–soil interaction, particularly under wet soil conditions [21,22].

Reducing inflation pressure promotes greater carcass deformation and increases the tire–soil contact area, phenomena that facilitate the release of soil accumulated between the tread lugs. This behavior is consistent with the findings of Taghavifar and Mardani [9], who demonstrated that changes in tire structural deformation significantly affect tire–soil interaction mechanisms and the distribution of stresses across the contact surface. Recent numerical simulations have further confirmed that lower inflation pressures increase the effective tire–soil contact area, improve contact stress distribution, and reduce localized stress concentrations responsible for soil adhesion to the tire [19,20].

The results obtained also corroborate the principles described by Wong [6], who emphasized that the dynamic deformation of the tire tread is one of the primary mechanisms responsible for removing soil adhered to the tread lugs. As the tire leaves the soil contact area, the elastic recovery of its structure promotes the detachment of material retained within the tread voids. Recent investigations based on finite element analysis have likewise identified tread flexibility, lug spacing, and carcass deformation as critical factors governing self-cleaning efficiency, traction generation, and soil disturbance in modern agricultural tires [21,22].

Furthermore, recent studies have demonstrated that lower inflation pressures can improve the operational performance of agricultural tires by increasing the contact area and reducing the average pressure applied to the soil. Ally et al. [1] reported that modifications in tread lug geometry and loading conditions significantly affect traction performance and tire–soil interaction efficiency, findings that are consistent with the behavior observed in the present study. Similar conclusions have been reported by recent laboratory, field, and numerical studies, which demonstrated that optimizing inflation pressure and tread geometry improves traction performance while reducing rolling resistance, soil compaction, and contact stresses [19,21].

When comparisons were made within each tire model, an inflation pressure of 1.2 bar promoted substantial gains in travel distance compared with inflation pressures of 1.6 and 2.0 bar. For tire P, for example, reducing the inflation pressure from 2.0 to 1.2 bar resulted in an increase of more than 120% in travel distance. A similar trend was observed for the other tire models, although with different magnitudes.

These results demonstrate that self-cleaning capacity depends not only on the structural characteristics of the tires but also on the proper adjustment of operating conditions. Therefore, selecting an appropriate tire model combined with proper inflation pressure management may represent an effective strategy for maximizing operational performance under field conditions, particularly in environments with high soil moisture and greater susceptibility to soil adhesion. Recent advances in tire–soil interaction modeling have demonstrated that the integrated optimization of tread geometry, inflation pressure, and tire loading is essential for improving traction performance while minimizing soil degradation and preserving soil structure [18,19,21].

When analyzing the soil release capacity of the tires, the analysis of variance revealed a significant effect of inflation pressure, tire model, and the interaction between these factors on the number of revolutions required to promote the disaggregation of soil adhered to the tires (Table 3).

The significant interaction between inflation pressure and tire model indicates that the effect of inflation pressure depends on the tire model evaluated. Therefore, tire performance was not consistent across the inflation pressure levels studied, justifying the analysis of the interaction effects (Table 4).

Table 3. Summary of the analysis of variance for the number of tire revolutions required for tread cleaning.

Source of Variation	DF	F-Value	*p*-Value
Blocks	3	99.12	<0.0001
Inflation Pressure	2	126.24	<0.0001
Tire Model	3	53.66	<0.0001
Inflation Pressure × Tire Model	6	145.21	<0.0001
Residual	33	–	–
CV (%)	–	1.77	–

Note: Data were log-transformed prior to analysis to meet the assumptions of normality and homogeneity of variances. The coefficient of variation (CV) was calculated based on the residual mean square of the transformed data.

Table 4. Number of tire revolutions required for soil removal from agricultural tires as affected by inflation pressure and tire model.

	Tire Model			
Inflation Pressure (bar)	**F**	**G**	**M**	**P**
1.2	17.0 ± 1.29 aB	19.0 ± 1.47 aB	9.0 ± 0.91 cC	15.0 ± 1.08 bB
1.6	17.0 ± 0.91 bB	17.0 ± 1.29 bB	23.0 ±1.78 aB	17.0 ±1.08 bA
2.0	19.0 ± 1.08 bA	22.0 ± 1.58 aA	24.0 ± 1.58 aA	18.0 ±1.08 bA

Values are presented as mean ± standard error (SE). Means followed by the same uppercase letter in the column and the same lowercase letter in the row do not differ significantly according to Tukey's test at the 5% probability level.

At 1.2 bar, tire M required the lowest average number of tire revolutions for soil removal (9 revolutions), representing the lowest value observed among the evaluated tire models. Tire M also showed the greatest increase in the number of revolutions required for soil removal as inflation pressure increased, rising from 9 revolutions at 1.2 bar to 24 revolutions at 2.0 bar. This increase suggests greater soil retention in the tread under higher inflation pressures and a consequent reduction in soil-removal capacity (Figures 3–5).

Similarly, tires G and F also exhibited an increase in the number of revolutions required for soil removal as inflation pressure increased. Tire G increased from 19 to 22 revolutions between the inflation pressures of 1.2 and 2.0 bar, while tire F increased from 17 to 19 revolutions. In contrast, tire P consistently exhibited the lowest values at the 1.6 and 2.0 bar inflation pressures, ranging from 17 to 18 revolutions, indicating greater efficiency in removing soil adhered to the tire tread (Figure 5).

This behavior suggests that specific tread design characteristics, such as lug geometry, lug spacing, lug height, and the void volume available for soil accommodation and subsequent ejection, directly influence self-cleaning efficiency. Under wet and cohesive soil conditions, smaller spacing between lugs may promote soil compaction and retention within the tread voids, hindering its subsequent ejection during tire rotation and, consequently, reducing self-cleaning capacity. Among the evaluated tires, tire P exhibited greater lug spacing, larger void volume, and greater lug height, characteristics that may favor both the accommodation of a larger amount of soil and its subsequent ejection during tire rotation. This combination of tread geometric features may explain the greater ability of tire P to maintain the tread voids relatively free of soil and, consequently, to travel longer distances before reaching tread saturation, particularly under the wet soil conditions evaluated.

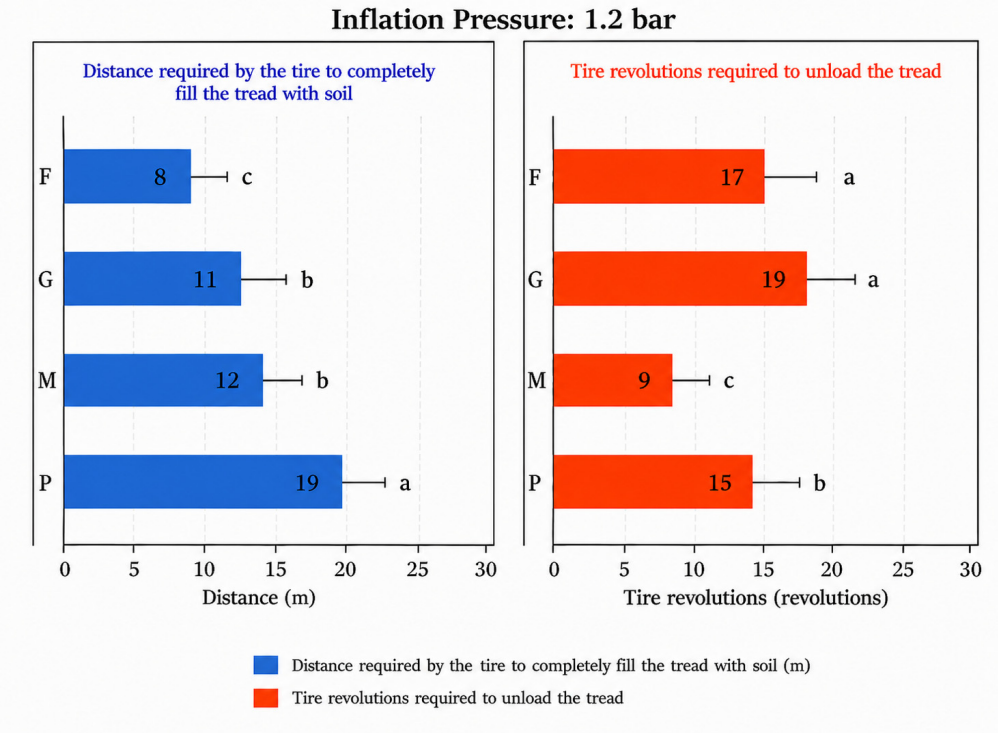


Figure 3. Effect of 1.2 bar inflation pressure on the distance traveled until tread saturation and the number of tire revolutions required to remove soil from the tire tread. Values are presented as means, and error bars represent the standard error of the mean (SE; n = 4). Different lowercase letters indicate significant differences among tire types according to Tukey's test ($p \leq 0.05$).

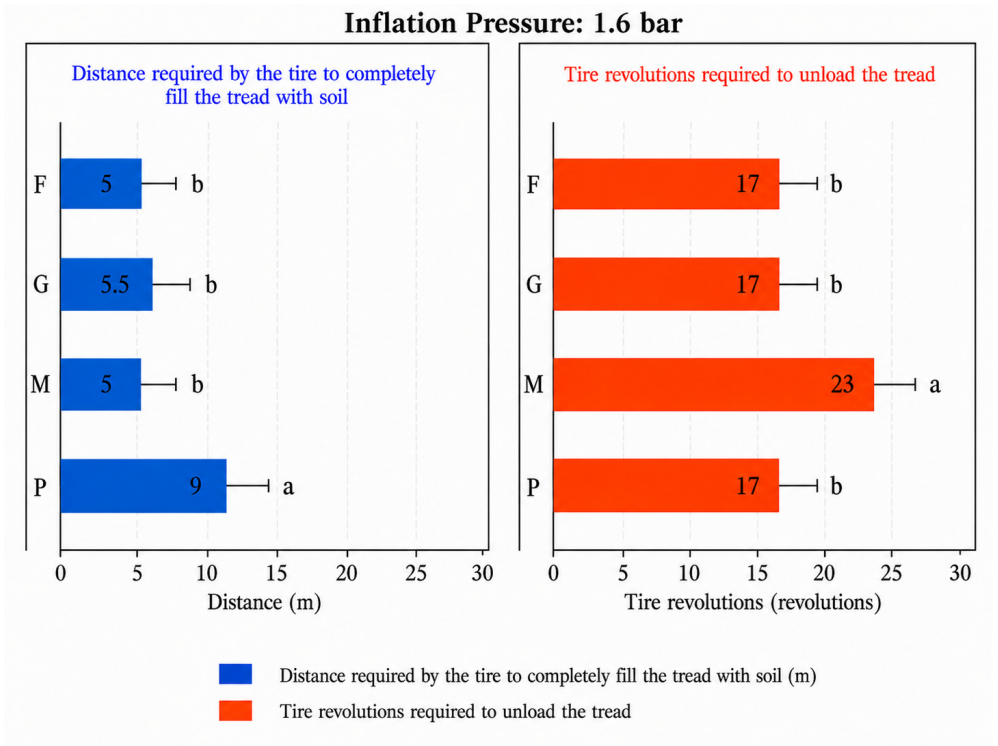


Figure 4. Effect of 1.6 bar inflation pressure on the distance traveled until tread saturation and the number of tire revolutions required to remove soil from the tire tread. Values are presented as means, and error bars represent the standard error of the mean (SE; n = 4). Different lowercase letters indicate significant differences among tire types according to Tukey's test ($p \leq 0.05$).

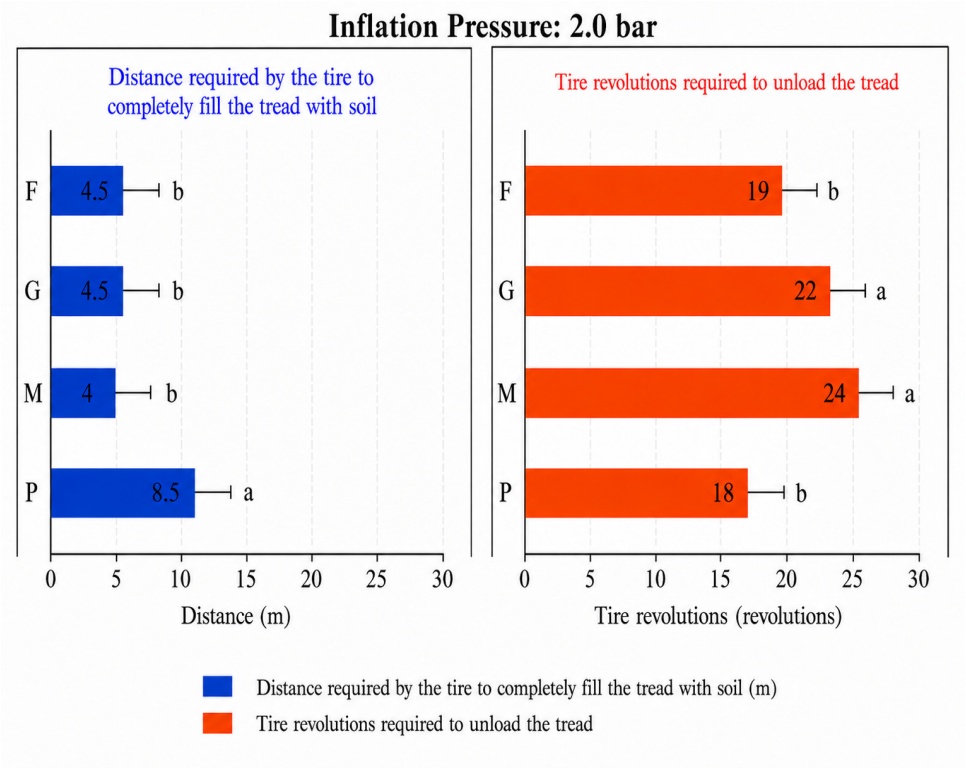


Figure 5. Effect of 2.0 bar inflation pressure on the distance traveled until tread saturation and the number of tire revolutions required to remove soil from the tire tread. Values are presented as means, and error bars represent the standard error of the mean (SE). Different lowercase letters indicate significant differences among tire types according to Tukey's test ($p \leq 0.05$).

The increase in the number of tire revolutions required for soil removal with increasing inflation pressure can be explained by the reduction in carcass deformation and the lower flexibility of the tread. Higher inflation pressures reduce the structural deformation of agricultural tires [9], which may modify the tire–soil contact conditions and the interaction between the tread lugs and the soil. Under lower inflation pressures, greater tire deformability may favor greater adaptation of the tread to the soil surface, affecting both soil accumulation between the lugs and the subsequent release of adhered soil. Conversely, higher inflation pressures reduce tire deformation and may alter the contact conditions, potentially affecting soil retention and release from the tread. Consequently, the mechanical action responsible for detaching soil particles adhered to the tread lugs may be reduced. Similar trends have recently been reported in numerical and experimental studies, which demonstrated that increasing inflation pressure reduces the tire–soil contact area and modifies stress distribution in the soil, which may influence soil adhesion and tire–soil interaction [8,18,23]. These changes may promote soil retention between the tread lugs, consequently reducing self-cleaning efficiency. Recent computational studies based on finite element analysis have also confirmed that both inflation pressure and tread geometry significantly influence contact stresses, soil deformation, and tire–soil interaction, reinforcing the importance of optimizing tire operating conditions [21,22].

The results obtained corroborate the principles of tire–soil interaction described by Wong [6], according to which cyclic deformation of the tire tread is one of the primary mechanisms responsible for expelling soil accumulated between the tread lugs. Recent studies have also highlighted the importance of tread deformation, lug spacing, and carcass flexibility in tire–soil interaction and soil release [22]. The superior performance of tire P in terms of the greatest distance traveled before tread saturation at all evaluated inflation pressures, and of tire M at 1.2 bar in terms of the number of tire revolutions required for soil

removal between the tread lugs, may be related to their larger R1W-type lugs and greater spacing between the lugs, as presented in Table 5. According to Ally et al. [1], variations in tread lug geometry can significantly affect both soil retention and soil release, consequently influencing the operational performance of agricultural tires. Finite element simulations have also demonstrated that optimizing lug spacing can modify tire–soil interaction and soil deformation, supporting the possible influence of tread geometry on the observed results [21].

Table 5. Main geometric and mass characteristics of the agricultural tires evaluated.

Tire	Lug Type	Lug Height (mm)	Number of Lugs	Void Distance Between Lugs (mm)	Circumferential Pitch (mm)	Mass (kg)	Load Index
P	R1W	56	21 × 2	215.4	265.4	195	155
F	R1	40.5	28 × 2	156	214.0	196	155
M	R1W	55	21 × 2	214	265.4	181	159/156
G	R1	41	26 × 2	164	214	184	155

The notation '21 × 2' indicates paired parallel lugs, with each pair consisting of two parallel lugs.

The increase in dynamic rolling radius with increasing inflation pressure, observed in all evaluated tires (Table 6), may be associated with changes in tire deformation under load. Higher inflation pressures are generally associated with reduced tire deformation, which can increase the effective rolling radius. However, carcass deformation was not directly measured in the present study. This behavior is consistent with the findings of Corrêa et al. [24], who demonstrated that inflation pressure significantly affects the dynamic rolling radius and dynamic rolling circumference of agricultural tires.

Table 6. Dynamic rolling radius as a function of tire inflation pressure.

	Inflation Pressure (bar)		
	1.2	1.6	2.0
Tire	Dynamic Radius (mm)		
P	863 ± 2.33	871 ± 2.67	877 ± 3.00
F	873 ± 2.53	881 ± 2.87	887 ± 3.20
G	860 ± 2.20	868 ± 2.60	874 ± 2.93
M	868 ± 2.40	876 ± 2.80	882 ± 3.13

Values are presented as mean ± standard error (SE), based on four replications.

The increase in inflation pressure generally reduced self-cleaning performance, both in terms of the distance traveled before tread saturation and the number of tire revolutions required for soil removal. Although higher inflation pressures increased the dynamic rolling radius, this increase did not result in improved tire performance. Higher inflation pressures increase tire structural stiffness and reduce carcass and tread deformation, which may limit lug flexibility and alter the mechanical interaction responsible for soil detachment from the tread voids. Under wet and cohesive soil conditions, this behavior may favor soil retention between the lugs and accelerate tread saturation, thereby affecting self-cleaning efficiency. However, the response was not uniform among the tire models, indicating that the effect of inflation pressure depends on tread characteristics and on the self-cleaning indicator evaluated.

Overall, the results demonstrate that both inflation pressure and tread design characteristics significantly influence the self-cleaning performance of agricultural tires. However, the significant interaction observed indicates that the response of each tire model depends on the applied inflation pressure, highlighting the importance of jointly considering these

factors when evaluating and managing agricultural tires [18,25]. Because carcass deformation, contact area, and stress distribution at the tire–soil interface were not directly measured in the present study, these mechanisms should be interpreted as possible explanations supported by the literature rather than as directly demonstrated causal relationships.

4. Conclusions

The evaluated indicators of tire self-cleaning were significantly influenced by inflation pressure, tire model, and their interaction. The lowest inflation pressure, 1.2 bar, resulted in the greatest distance traveled before tread saturation under the wet soil conditions evaluated. Tire P exhibited the greatest distance traveled before tread saturation at all evaluated pressures, reaching 19.0 m at 1.2 bar, 9.0 m at 1.6 bar, and 8.5 m at 2.0 bar. In general, increasing inflation pressure reduced the distance traveled before tread saturation. For soil removal after tread saturation, tire M at 1.2 bar required approximately 9 tire revolutions to reduce the adhered soil to the 10% endpoint, representing the lowest number of revolutions observed for this indicator. At 2.0 bar, tires P and F required 18 and 19 revolutions, respectively, with no significant difference between them, whereas tires G and M required 22 and 24 revolutions, respectively. These results demonstrate that the response of agricultural tires to inflation pressure depends on both the tire model and the self-cleaning indicator evaluated. Therefore, tread design characteristics and appropriate inflation pressure adjustment should be jointly considered when evaluating the self-cleaning behavior of agricultural tires operating under wet soil conditions.

Author Contributions: Conceptualization, T.M.M. and I.Z.; Methodology, T.M.M., I.Z., L.M., S.M. and R.M.F.; Validation, T.M.M.; Formal analysis, T.M.M.; Investigation, T.M.M.; Resources, T.M.M.; Data curation, T.M.M.; Writing—original draft, T.M.M.; Writing—review & editing, T.M.M.; Visualization, T.M.M.; Supervision, T.M.M.; Project administration, T.M.M. Funding acquisition, T.M.M. and I.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Prometeon Tyre Group, project number 4024085.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: Institute of Agricultural and Environmental Sciences of the Federal University of Mato Grosso (UFMT) and Prometeon Tyre Group.

Conflicts of Interest: The authors Igor Zucato, Luiz Mari, Suyami Maruyama, and Renato Martins Fantini are employees of Prometeon Tyre Group. This study was conducted as part of a collaborative research project between the Federal University of Mato Grosso (UFMT) and Prometeon Tyre Group and received financial and institutional support from Prometeon Tyre Group. The above-mentioned authors contributed to the study methodology, interpretation of the results, manuscript preparation, and approval of the final version of the manuscript. They did not participate in the collection of experimental data or the statistical analyses. Professor Thiago Martins Machado (Federal University of Mato Grosso, UFMT) participated in all stages of the study, including the experimental design, supervision of the research, collection of experimental data, statistical analyses, interpretation of the results, manuscript preparation, and the decision to submit the manuscript for publication. The authors declare that the scientific conclusions presented in this manuscript were reached independently and were not influenced by the funding organization or the employment relationships.

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