

Effects of Different Tire Configurations on Tractor Performance

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Abstract: The effects of tire ply constructions (radial and bias) and tire arrangements (singles and duals on rear the axle) on tractor performance were evaluated for 2 gear levels on 2 different fields covered with wheat stubble and having different soil types, clay and sandy-loam. For this purpose, the tractor's overall efficiency, specific fuel consumption, and slip values were determined using parameters measured in the study. The results showed that the use of radial tires provided some advantages. For example, overall tractor efficiency with radial tires instead of bias tires increased by 3.44%, while specific fuel consumption decreased by 3.08% on average. When operating with dual tires instead of single tires, overall efficiency increased by 14.73%, while specific fuel consumption decreased by 12.77% on average. Radial-ply tires did not provide a considerable reduction (6.7% on average) in terms of slip compared to bias-ply tires, while the use of duals reduced the slip by 34% on average. Variance analysis was performed and evaluated to determine the statistical significance of effects on the performance of the factors and their interactions. According to the statistical results, the best results were obtained with radial tires in dual configuration.

Key Words: Tractor Performance, Tire Configuration, Bias and Radial Tires

Farklı Lastik Tekerlek Düzenlemelerinin Traktör Performansı Üzerindeki Etkileri

Özet: Bu çalışmada, farklı toprak yapısına sahip (killi, kumlu-tınlı) anızla örtülü iki arazide; iki farklı yapıda (diagonal ve radyal) lastik tekerlek ve farklı düzenlemelerinin (arka aks üzerinde tek ve çift lastik) traktör performansı üzerindeki etkileri, iki vites kademesinde deneysel yöntemlerle elde edilen veriler yardımıyla değerlendirilmiştir. Bu amaç için, denemelerde elde edilen veriler yardımıyla, traktörün genel verimi, özgül yakıt tüketimi ve patinaj değerleri belirlenmiştir. Sonuçlar, radyal ve arka aks üzerinde çift lastik tekerlek kullanımının bazı avantajlar sağladığını göstermiştir. Diagonal lastik yerine radyal lastik kullanımı, traktör genel verimini ortalama %3.44 oranında artırırken, özgül yakıt tüketimini ise ortalama %3.08 oranında azaltmıştır. Arka aks üzerinde tek yerine (ek ağırlık) çift lastik (ek lastik) tekerlek kullanılması durumunda, traktör genel verimi ortalama %14.73 oranında artarken, özgül yakıt tüketimi ise ortalama %12.77 oranında azalmıştır. Radyal lastik kullanımı, diagonal lastik kullanımına kıyasla patinaj değerini ortalama %6.7 oranında azaltırken, çift lastik tekerlek kullanımı tek lastik tekerlek uygulamasına kıyasla patinaj üzerinde ortalama %34 oranında bir azalma sağlamıştır. Denemelerde ele alınan faktörlerin gerek ayrı gerekse oluşturdukları etkileşimlerle; traktör performansı üzerindeki etkilerinin istatistiksel olarak önemini ortaya koyan varyans analizi yapılmış ve sonuçlar değerlendirilmiştir. Çalışmada en iyi sonuçlar, Radyal lastik ve ek lastik tekerlek etkileşimlerinde elde edilmiştir.

Anahtar Sözcükler: Traktör verimi, Lastik tekerlek düzenlemeleri, Diagonal ve radyal lastik

Introduction

Modern agriculture requires the use of larger machinery and equipment. The trend toward total mechanization of farm operations makes the cost of machinery and equipment a major portion of the total farm expenses. The tractor is a principle power unit used with most equipment and machines. Therefore, the farm manager is dependent upon the tractor to perform most farm operations. On the other hand, the goal of farm

machinery management is to increase farm profits through the optimum selection and management of tractors and equipment. Unless the engine power of a tractor is converted to traction power efficiently, either more energy is required to complete the operation or the work cannot be accomplished. Tractor working capacity is restricted by the losses along the power train. Approximately 12-18% of the engine power output is lost before it reaches the tractor's axle (Sabanacı, 1997).

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This loss represents the difference between engine and axle power. Another important portion of the losses occurs between the axles and the ground as 20-40% (Mowitz and Finck, 1987). Since increasing the tractive performance is the key for operational and cost effective practices, tire selection and arrangement should be investigated. Many researchers have focused on this subject.

Gee-Clough et al. (1977) performed traction tests on 17 different surfaces using radial and bias-ply tires with the same dimensions. They found that the radial-ply tires gave an average 5-8% increase in the dynamic traction ratio (DTR) at 20% slip. Mueller and Treanor (1985) conducted extensive testing on a 4-wheel drive (4WD) tractor, comparing bias and radial-ply tires. Results showed that the radial-ply tires are significantly better than the bias-ply tires for field productivity and drawbar power at 8.05 km h⁻¹ field speed. Radial-ply tires also had less wheel slip, but the improvement was not statistically significant. Wulfsohn et al. (1988) examined the traction properties of radial and bias-ply tires on tilled clay-loam soil. They reported that the average tractive efficiency increased 6.8% with the use of large radial-ply tires instead of large bias-ply tires over the 0-30% slip range. Hutching (1983) carried out field experiments with single and dual tractor tires. He concluded that there was little difference between the performances of the dual and single tires, when ballasted to the same level. Jurek and Newendrop (1983) found only a 3% to 6% improvement on average in fuel economy when using dual tires over single tires on a 2WD tractor in tilled and untilled soil. Kucera et al. (1985) conducted field studies with front-wheel assist (FWA) tractors configured with single or dual tires. They reported that, on untilled wheat stubble ground, a FWA tractor equipped with singles was more fuel efficient than a FWA tractor equipped with duals.

In Turkey, the number of tractors in the economic tractor park (up to 15 years old) is 550,000. Only approximately 1% of the tractors have a PTO (power take-off) power of 70 kW or higher. In addition, the share of the tractors within the power range of 60-69 kW is about 3% (Sumer et al., 2003). The main reasons for having low powered tractors are small sized farms (6.1 ha on average) and the low purchasing power of the farmers (Say, 2003). The tractors used on Turkish farms are often insufficient during some farm operations that

require relatively high tractive force, such as combined tillage, deep plowing, and subsoiling. This problem can partially be prevented by adequate applications related to tire construction and tire arrangements.

There are no published studies related to tractor performance comparisons for different tire types and arrangements for the soil conditions of the Çukurova region, which is one of the major agricultural production areas in Turkey.

The objective of this research was to determine tractor performance under real working conditions for selected factors and their interactions for the benefit of farmers and tractor dealers. In the study, the tractive performance of a mechanical front wheel drive (MFWD) tractor was examined based on overall tractor efficiency, specific fuel consumption, and slip. Singles versus duals on the rear axle and bias-ply tires versus radial-ply tires, which are used very seldom in Turkey, were compared. Field experiments were carried out on 2 fields having different soil types and covered with wheat stubble.

Materials and Methods

Experiment Fields

Experiments were performed on 2 fields with different soil types, clay and sandy-loam. Both fields were covered with wheat stubble. The clay soil field was located at the Research and Implementation Farm of the University of Çukurova at Adana, Turkey. The sandy-loam soil field was located at another farm near the University of Çukurova. Some soil characteristics of the experiment fields in average values are given in Table 1.

The moisture content values of the clay soil field were higher than those of the sandy-loam soil field in the 10-20 cm and 20-30 cm profile depths. On the other hand, in the profile depth of 0-10 cm, the moisture content of the clay soil field was lower than that of the sandy-loam soil field. The bulk density values of the sandy-loam soil field were higher than those of the clay soil field. The cone index values measured simultaneously while taking the soil samples increased along the profile depth in both fields. There were no considerable differences between the cone index values of the clay and sandy-loam soil fields at a plowing depth of 23 cm. Cone index values were 1275 kPa and 1300 kPa on average in the clay and sandy-loam soil fields, respectively.

Table 1. Some soil characteristics of the experiment fields.

Field	Profile Depth (cm)	Moisture Content (d.b.), %	Bulk Density (gcm ⁻³)	Cone Index (kPa)
Clay (34.1% sand; 23.7% silt; 42.2% clay) Area=0.3 ha	0-10	8.02	1.25	1125
	10-20	10.77	1.29	1650
	20-30	14.09	1.34	1970
Sandy-Loam (70.5% sand; 17.2% silt; 12.4% clay) Area=0.3 ha	0-10	9.69	1.64	958
	10-20	8.82	1.65	1865
	20-30	6.11	1.61	2175

Tractor, Equipment, and Tires

A New Holland 80-66 MFWD tractor with a PTO power of 63 kW was instrumented to measure tractive force, ground speed, fuel consumption, and slip. The tractor was loaded with a 3-furrow half-turn plow in each application. Details of the tires and the field tests are shown in Table 2. In Turkey, tractors within the power range of 60-69 kW are generally equipped with tires of the sizes selected in this study (Table 2).

A mounting apparatus, which provides 10-cm spacing between the tire sidewalls and which is 45 kg (Figure 1) was designed and built for the dual tire arrangement on the rear axle.

In the field experiments, ground speed, tractive force, fuel consumption, and slip were measured and recorded using a microcomputer-based data acquisition system. This measurement system, developed by Akıncı et al. (1994), consists of 3 force measurement clevis pins, a magnetic sensor, a fuel flowmeter, a data acquisition card, and a portable computer that can easily be mounted on the tractor.

Experimentation

The field experiments were established with 3 factors based on a randomized complete block design with 4 replications. The 3 factors were:

Table 2. Details of the tires and the field tests.

Tires and Ballasting Regular tread (R-1)			Rear Axle	
			Singles	Duals
Bias-ply:	Front	12.4/11x24	138 kPa (20 psi)	138 kPa (20 psi)
	Rear	18.4/15x30	111 kPa (16 psi)	111 kPa (16 psi) ^a
Radial-ply:	Front	12.4/11x24	124 kPa (18 psi)	124 kPa (18 psi)
	Rear	18.4/15x30	97 kPa (14 psi)	97 kPa (14 psi) ^b
Weight			4290 kg	4255 kg
Static Weight Distribution			Front: 40% Rear: 60%	Front: 40% Rear: 60%
Gears:	G1, I-4 G2, II-2			
Fields:	Clay and Sandy-loam			
Surface:	Wheat stubble			

^a Inner rear bias-ply tire inflation pressure. Outer rear bias-ply tire inflation pressure was 97 kPa (14 psi).

^b Inner rear radial-ply tire inflation pressure. Outer rear radial-ply tire inflation pressure was 83 kPa (12 psi).

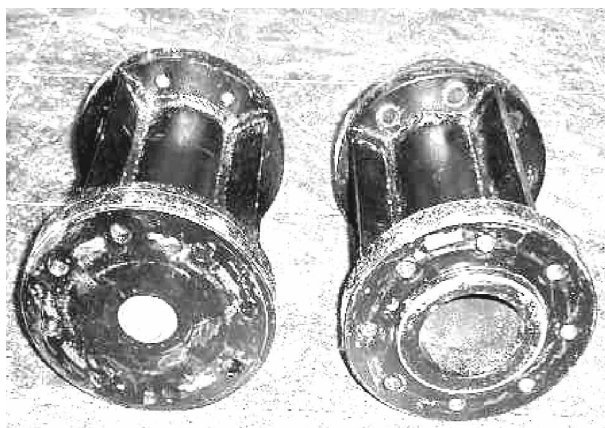


Figure 1. Apparatus for mounting outer dual wheel to inner wheel.

- tires (bias-ply and radial-ply tires on the rear axle),
- tire arrangement (single and dual tires), and
- gear levels (I-4 and II-2).

In the singles, experiments were carried out with 150 kg of ballast on each tire rim on the rear axle and 300 kg of ballast on the front of the tractor. High-powered tractors are sold with total 300 kg of ballast attached to the rear axle in Turkey. Farmers use tractors with these ballasts in most agricultural operations. As an alternative to ballast use with singles, field experiments were also conducted with duals on the rear axle. In this arrangement, as suggested by previous research, the inflation pressure of the outer tires was 2 psi less than that of the inner tires. Kraving (1986) reported that this practice puts less stress on the outer tire, axle and mounting apparatus. Singles and duals were examined separately using bias and radial-ply tires on wheat stubble surfaces with 2 different gear levels (I-4 and II-2), which gave a common ground speed for plowing. The tractor was operated at full throttle in each selected gear level and the differential lock was engaged during all tests.

Tractive force was measured using the 3 force measurement pins connecting the tillage equipment to the tractor through the 3 hitch points. Slip was measured using a magnetic sensor perceiving 8 signals in 1 revolution of the rear tire.

Tractor performance is generally evaluated using TE (tractive power/axle power) and DTR (tractive force/dynamic axle load) criteria. TE and DTR are concerned with losses caused by tire-surface interactions

in the traction system, while overall tractor efficiency is a parameter that takes into account the losses in the engine, transmission, and traction system (Souza et al., 1994). In this study, we used overall tractor efficiency, specific fuel consumption, and slip since these are the more objective comparison parameters for farmers and farm managers.

The overall tractor efficiency was calculated with the following equation (Sabancı, 1997; Macmillan, 2002):

$$\eta = \frac{N_T}{N_F} \quad [1]$$

where

N_T = Tractive power (kW),

N_F = Fuel power (kW).

Fuel power was calculated from equation (2).

$$N_F = \frac{BH}{3600} \quad [2]$$

where

B = Fuel consumption (kg h⁻¹),

H = Energy value of diesel fuel (41,870 kJ kg⁻¹).

Tractive power was calculated from equation (3).

$$N_T = \frac{FV}{1000} \quad [3]$$

where

F = Tractive force (N),

V = Ground speed (m s⁻¹).

Results and Discussion

Figure 2 shows the effects of the factor interactions on ground speed, tractive force, tractive power, and fuel consumption. There were small differences in the ground speeds observed in each field (Figure 2a). The ground speeds for II-2 gear (G2) were higher than those for I-4 gear (G1). The dual arrangement provided slightly higher ground speeds due to its reducing effects on slip.

Table 3 shows ground speeds depending on interactions for the selected gears according to the experiment fields. Radial-ply tires provided small advantages (about 3% increases) in average ground

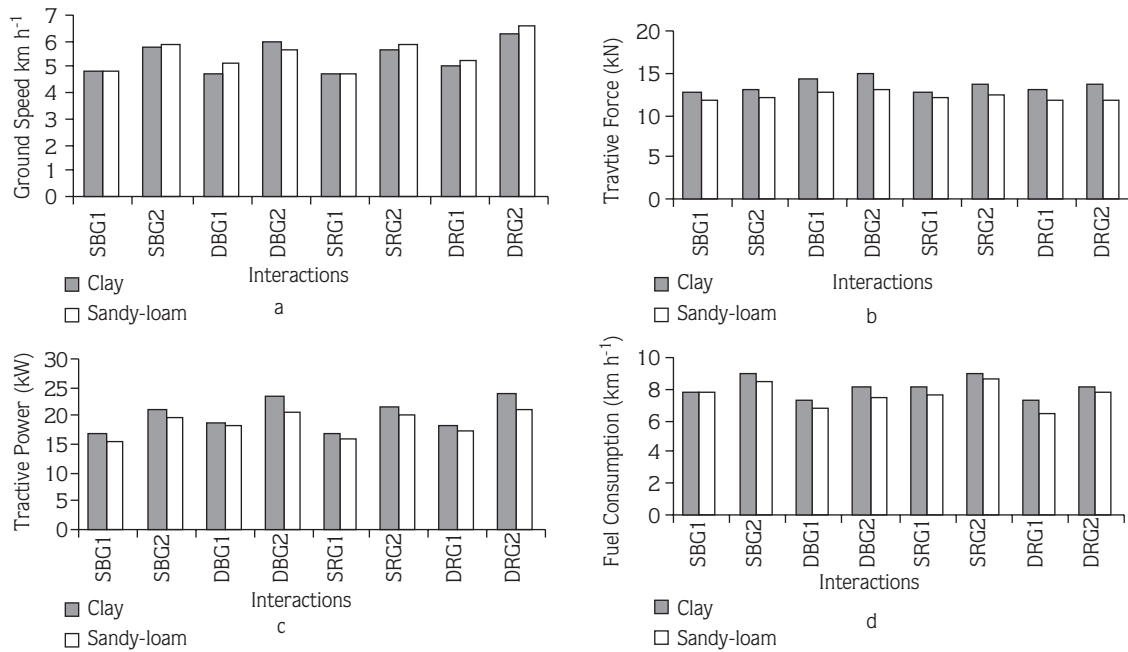


Figure 2. The effects of the interactions of factors on ground speed, tractive force, tractive power and fuel consumption (S-single, D-Dual, B-Bias, R-Radial, G-Gear).

Table 3. Ground speeds and slip values for the selected gear levels.

Gear Levels	Interactions	Clay		Sandy-loam	
		Ground speed (km h ⁻¹)	Slip (%)	Ground speed (km h ⁻¹)	Slip (%)
I-4 (G1)	SBG1	4.83	15.85	4.83	17.31
	SRG1	4.76	14.11	4.77	15.20
	DBG1	4.70	11.68	5.18	13.01
	DRG1	5.04	9.96	5.22	9.94
II-2 (G2)	SBG2	5.78	20.10	5.83	19.37
	SRG2	5.69	20.80	5.88	20.49
	DBG2	5.93	13.08	5.76	12.61
	DRG2	6.24	12.21	6.33	12.05

speed compared to bias-ply tires on both research fields. In addition, dual tires provided approximately 7% ground speed increase due to 34% slip reduction on average on both fields.

The tractive force values on the clay soil were slightly higher than those on the sandy-loam soil, as expected (Figure 2b). Furthermore, calculated tractive power

values in the clay soil were greater than those in the sandy-loam soil (Figure 2c).

Fuel consumption was slightly higher (approximately 5% on average) in clay-soil conditions than in sandy-loam soil condition (Figure 2d). In addition, fuel consumption values for duals were less than those for singles. This can be attributed to the advantage of the 7% ground speed

increase when working with duals. It was found that radial-ply tires did not provide any considerable advantage in terms of fuel consumption compared to bias-ply tires (Figure 2d).

An analysis of variance was performed according to randomized complete block design with 4 replications to determine the effects of factors on the overall tractor efficiency, specific fuel consumption, and slip. The results indicated that the tire construction (bias or radial-ply) had no statistically significant effect on the overall tractor efficiency, specific fuel consumption, or slip on eighter of the experiment fields. However, both the tire arrangements (singles or duals) and the ground speed were found to significantly affect overall tractor efficiency, specific fuel consumption, and slip ($P < 0.01$).

Although the tire construction as a single factor did not result in any remarkable change in the specific fuel consumption, duals with the II-2 gear (G2) interaction markedly reduced the specific fuel consumption compared to the other interactions, particularly for the single tire arrangement with the I-4 gear (G1) interaction (Figure 3).

The specific fuel consumption decreased 14.15% in clay soil and 11.39% in sandy-loam soil with the duals compared to the singles. Minimum specific fuel consumptions, obtained in the DRG2 interaction, were 356.90 g kW-h⁻¹ and 388.30 g kW-h⁻¹ for clay and sandy-loam fields, respectively, while the maximum specific fuel consumptions, in the SRG1 interaction, were 479.27 g kW-h⁻¹ in clay soil and 487.75 g kW-h⁻¹ in sandy-loam soil. It was found that the difference between the specific fuel consumption values of the triple interactions that

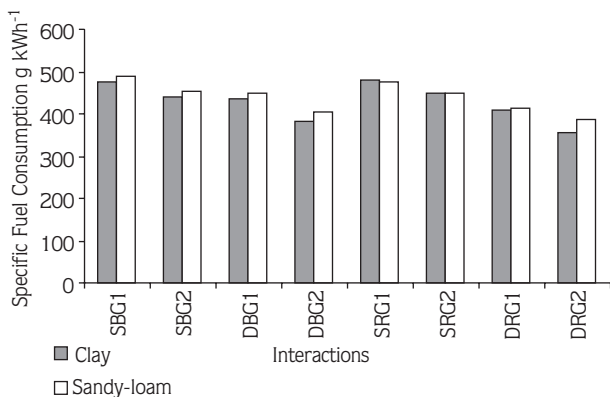


Figure 3. The effects of interactions on specific fuel consumption (S-single, D-Dual, B-Bias, R-Radial, G-Gear).

provided the maximum and minimum specific fuel consumption values was about 25% on average.

Duals with G2 interactions markedly increased the overall tractor efficiency compared to the other interactions, particularly for the singles with G1 interactions (Figure 4).

The overall tractor efficiency was slightly increased by using radial-ply tires (3.52% in clay soil and 4.90% in sandy-loam soil); however, the difference was not statistically significant. The use of duals increased overall tractor efficiency by 16.95% in clay soil and 13.40% in sandy-loam soil. Overall tractor efficiency values for all interactions in clay soil were slightly higher than those in sandy-loam soil.

The maximum overall tractor efficiency was obtained in the DRG2 interaction, 23.50% and 22.20% for clay and sandy-loam, respectively, while the minimum overall tractor efficiency was 17.95% in the SRG1 interaction in clay soil and 17.60% in the SBC1 interaction in sandy-loam soil. Overall tractor efficiency was increased by 28% on average for maximum and minimum values of triple interactions.

Radial-ply tires did not provide a considerable reduction (6.0% in clay, 7.4% in sandy-loam) in terms of slip compared to bias-ply tires, while the use of duals reduced slip by 33.82% in clay and 34.25% in sandy-loam. Slip values in clay and sandy-loam soil were similar because both fields were covered with wheat stubble. The minimum slip values were obtained with the DRG1 interaction, about 9.9% for both fields; while the maximum slip values, with the SRG2 interaction, were about 20.6% for both fields (Figure 5).

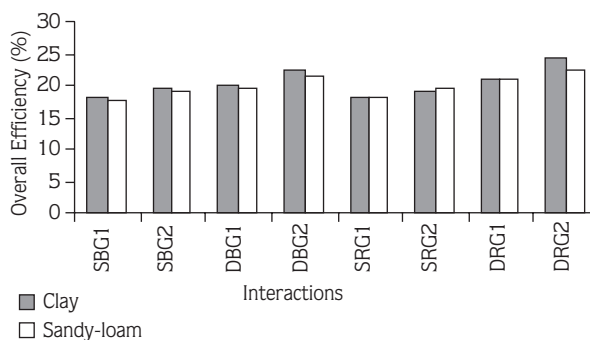


Figure 4. The effect of the factor interactions on overall tractor efficiency (S-single, D-Dual, B-Bias, R-Radial, G-Gear).

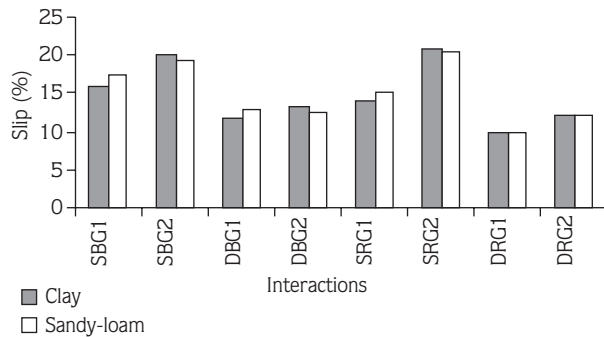


Figure 5. The effects of the factor interactions on slip (S-single, D-Dual, B-Bias, R-Radial, G-Gear).

The overall tractor efficiency, specific fuel consumption, and slip were not considerably changed by soil type due to the fact that the experiment fields had similar surface and soil characteristics.

Various studies have compared the tractive performance of radial-ply and bias-ply tires and different arrangements of them. Radial ply-tires were found to cause significant increases in average pull when run in the 0-30% slip range (Forrest et al., 1962; Vanden and Reed, 1962). Thaden (1962) found that the tractive advantage of radial-ply tires drops off at higher slip. Hausz (1985) stated that the tractive advantages of radial-ply tires result from their deflection characteristics and resulting pressure distribution. This is because the lugs on the radial-ply tire (near the center of tread) have a much more uniform pressure distribution on them, and so will bite into the soil more uniformly. Taylor et al. (1976) compared the tractive performances of a radial-ply and a bias-ply tire of the same size and shape in a range of soil conditions. Their results showed that the radial-ply tires had little advantage in terms of tractive efficiency. Other researchers stated that radial-ply tires were more durable than bias-ply tires on firm soil. Kraving (1986) sums up the advantages of radial tires over bias-ply tires as follows: increased tire footprint, additional tractive efficiency, reduced wheel slip, smoother ride in the field, and improved fuel economy. Hoffman (1983) reported that the tractive efficiency values increased by 8-9.5% with the use of radial-ply tires instead of bias-ply tires on different soils. Grisso et al. (1992) reported that firm soil conditions reduced the advantages of radial tires.

Bashford et al. (1987) conducted field experiments with single and dual tractor tires. They concluded that the use of dual tires instead of single tires provided little advantage in terms of tractor performance on wheat stubble surfaces. Clark and Liljedahl (1969) compared single and dual tires, and concluded that the performance of the dual tires was better than that of the single tires in soft soil. In firm soil, however, there was no significant difference between the 2 arrangements. McLeod et al. (1969) reported that dual tires gave generally better tractive performance than single tires, but the difference was less pronounced in clay soil than in sandy soil.

The results reported in this study were in general agreement with other relevant research. However, there are some differences in increase and decrease ratios determined for definite working conditions. These differences might result from diversities in working conditions and performance evaluation parameters.

Conclusions

According to the experimental data, radial-ply tires provided a slight advantage over bias-ply tires. Overall tractor efficiency was increased by 3.44%, while specific fuel consumption was decreased by 3.08% on average with radial-ply tires compared to bias-ply tires.

When operating with duals instead of singles, overall tractor efficiency was increased by 14.73%, while specific fuel consumption was decreased by 12.77% on average.

The best results in this study were obtained with radial-ply tires in dual configuration. Maximum overall tractor efficiency, minimum specific fuel consumption, and minimum slip were obtained by the DRG2 interaction in both soils.

It was concluded that duals, especially during some farm operations, such as deep plowing, combined tillage, and subsoiling machines, could be useful in terms of farm economy since the agricultural operations can be completed on time with an increase in ground speed (7% increase) and using machinery with higher working capacity.

The dual wheel mounting apparatus designed and built in this study can be easily and securely adopted for dual arrangement in Turkish agricultural conditions.

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