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TRACTIVE PERFORMANCE FOR 4-WD TRACTORS UNDER DIFFERENT TIRE - BALLAST COMBINATIONS

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ABSTRACT

The tractive performance and fuel economy of a 4-WD tractor was investigated under different tire-ballast combinations. Single tires and dual tires, with and without ballast, were used. The tests were conducted in three soil conditions at various drawbar loads for two transmission gear settings. Performance curves are presented and the results indicated that: the all singles all ballasted outperformed the all dual nonballasted and the all singles nonballasted arrangements in soft soil. Single wheel combinations had better tractive performance than the two dual wheel combinations in medium (tilled) soil except at high drawbar loads. In stubble (firm) soil, no clear advantage occurred for any wheel or ballast combination. No significant differences in specific fuel consumption occurred for the various wheel and ballast combinations. For each combination and for all soils, fifth gear provided better specific fuel consumption than fourth gear.

INTRODUCTION

Burt et al. (1983) stated that research results throughout the world show that from 20 to 55 percent of the energy delivered to the drive wheels of tractors is wasted in their traction elements. They conducted field tests to show that for a given drawbar pull, the tractive efficiency of both radial-ply and bias-ply tires can be maximized by selecting appropriate levels of dynamic load and inflation pressure. They found a range of differences, depending on soil conditions and tire construction.

Dwyer and Pearson (1976) reported that the four tires of the four wheel drive tractor were assumed to be equivalent to two wheel each of diameter equal to the sum of the diameters of the front and the rear wheel and of width equal to the average of the widths of the front and rear wheel. This was considered to be the most reasonable method of treating wheels in the some track because the width of soil disturbed would be no greater than with one wheel but the rearward deformation of the soil would be equivalent to that produced by giving a larger ground contact area and, therefore, of larger diameter. The load on each of these two theoretical equivalent wheels was assumed to be equal to half the to total weight of the tractor and implement.

Abdel- Mageed (1994) concluded that the difference of slip from 7.1 up to 16% can be encountered as a result of the no - load surface type (4 WD and 2WD, respectively). Meanwhile the tractor in the 4WD mode delivered from 9 to 20.5% higher power and from 4 to 18% higher output rate than the 2WD. The 4WD mode enables the tractor to use its power at lower speed closer to the practical speed than the 2WD does. In general, the 4WD tractor was found superior than the 2WD tractor in all comparison criteria and the former is recommended to work the heavy draft implements

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Hashish et. al (1997) compared the traction performance between two and four - wheel drive tractors on a sandy soil and three soil conditions, with two sizes of rear wheel, 18.40*30 and 14.00*38 traction power, forward speed, fuel consumption, specific fuel consumption and slippage were measured. The results showed that the four-wheel drive tractor with rear tire size of 14.00*38 improved the traction power and slippage. Also, It also saved and improved the specific fuel consumption than the two - wheel drive tractor with 18.40*30 rear tire sizes.

Hutchings (1983) concluded from a field trails with single and dual tractor wheels one series of tests compared (23.1-34") single wheels to a dual arrangement of (23.1-34") wheels used on the inside and (18.4-34") wheels added as the outside dual. A second series of trials used (30.5-32") wheels as a single wheel compared to dual (18.4-38") wheels. For each series of tests, ballast was adjusted so that total tractor mass was nearly the same for each wheel arrangement. He concluded that both series of tests had little difference between performance of the dual and single wheels, when ballasted to the same level. However, where flotation was a problem, dual increased contact area thereby resulting in less sinkage and rolling resistance. Therefore, there are factors other than tractive performance that need to be considered when making choice between single or dual wheels.

Bloome et al.(1983) made a comparison of the ballast recommendations of a number of investigators. As a practical aid for farmers, they stated that ballasting recommendations should be based on known or easily determined parameters, such as PTO power, static mass and indicated speed. They concluded that ballasting should be approximately the same for two-wheel and for four-wheel drive tractors. Optimum ballast for the power-limited and for the traction-limited cases was expressed by a simple equation in terms of ground speed and mass per unit of PTO power (kW).

Larsen and Erickson (1981) conducted field measurements on 33 different four-wheel drive tractors. Drawbar power ranged from 45 to 360 horsepower. These tests showed that a large portion of the tractors were underutilized. The average observed power was 59 percent of the Nebraska Test power. Operating speeds were normally lower than recommended for good drive train life and the implements used were smaller than optimum for the size of tractor. Few farmers took advantage of the inherent fuel saving through use of the gear-up throttle-down mode of operation, although excess tractor power was available.

Friesen and Domier (1967) reported the effect of soil conditions on tractive efficiency on a four-wheel drive tractor. In the Red River clay, maximum tractive efficiency as high as percent was observed, while in the fine sandy loam, the maximum tractive efficiency was only 62 percent. The effect of ballast was also measured. With fluid ballast, the total weight was 91 kN, without fluid ballast; the total tractor weight was 67 kN. Three gears were selected for their test runs in Osborne clay. In all the selected gears, the ballasted condition gave better performance in terms of tractive efficiency.

El Ashry (1994) compared the performance of radial ply and bias tires. He was found in the tilled sandy loam soil condition that: the large tires performed better than the small tires. The radial ply tires performed better than the bias bly tires. Increasing the dynamic load increased the performance. Increasing the tires Inflation pressure (25% for large tire and 35% for small tire) did not influence the performance.

In the past 30 years considerable research has been conducted to study factors affecting tractive performance of tractors. However, most of this work has dealt with single tires or two-wheel drive tractors. Recently more attention has been paid to four-wheel drive tractors. Four-wheel drive tractors represent a significant portion of the total equipment investment on a farm. The operating cost of these units can be minimized if the tractor's power is used efficiently.

The objectives of this wok were: to determine the optimum tire and ballast arrangement for three soil conditions in terms of tractive efficiency and to investigate the fuel economy of a four - wheel drive tractor under various tire arrangements, ballast conditions, for three soil conditions and two gear selections.

TEST EQUIPMENT AND PROCEDURE

The tractive and fuel performance tests were carried out with a MF4800 four wheel drive tractor (133.7 kW engine power). This tractor was equipped with 23.1*34 tires and inflated to 85 kPa. Four parameters: draft, fuel flow, ground speed and slip were determined . A 11 tine chisel plow was used to provide a drawbar load.

Tractor ground speed and slip ratio were measured by fifth wheel. It consists of three photo-coupler units attached to the two driving wheels and the fifth wheel hubs, and a digital readout counters which display the actual number of revolutions for each of the two drive wheels and the fifth wheel. In addition, a built-in digital stop watch measures the time elapsed during each run. Additional detail describing the instrumentation has been provided by Elashry 1992. Drawbar pull was measured by a hydraulic dynamometer .

A separate apparatus (Figure 1) was used for fuel consumption (Elashry and Aboamera,1995). It consisted of a secondary tank of ten liters capacity with a level marked tube on its top. It was installed and connected to the tractor fuel tank through hoses and two 2 -way valves. The secondary tank was first filled with fuel to the mark on the top of the tab. During the actual run, the tractor was first let go on its fuel from the main tank. To measure the fuel consumption during a specific field operation, the secondary tank was utilized through the valves 1 and 2. At the end of the run, the valves were refilled off. The secondary tank was refilled to the mark on the tube from a graduated cylinder and amount of reful was taken as the fuel consumed during the specific operation duration. The fuel consumption measurement is resented to for the estimation of the fuel thermal power related to a certain tractor-implement combination, carrying out a certain job.

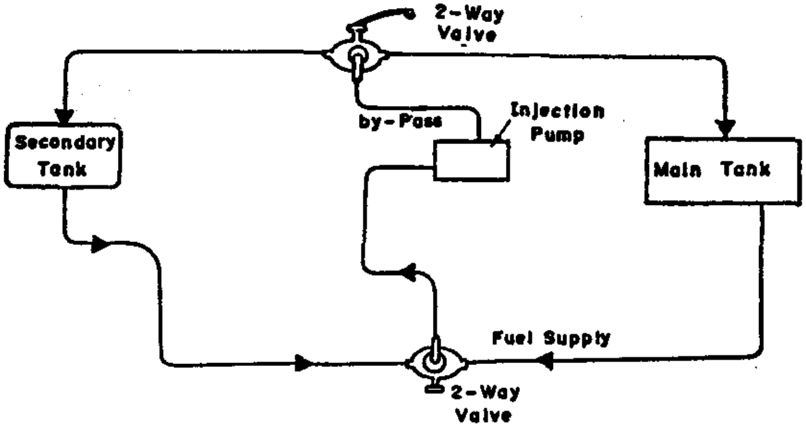

Figure (1): Apparatus used for measuring fuel consumption.

The tests were conducted in three different soil conditions, namely: soft, tilled (medium) and wheat stubble (firm). Soil type, cone index values and moisture levels are given in Table (1). Three tire and ballast combinations were used. These combinations included all singles nonballasted, all singles all ballasted and all duals non ballasted. The static weight distribution for each combination is shown in Table(2). For each tire and ballast combination, tests were conducted in fourth and fifth gear, which were considered to be the normal working gears for the tractor. The traveling speed varied from 6.8 to 8.0 km/h in fourth gear and from 8.2 to 10.2 km/h in fifth gear. In each gear test four load levels were tested, 5 to 9 kN (low), 16 to 19 kN (medium), 25 to 30 kN (high) and 35 to 40 kN (maximum). The drawbar load was adjusted by changing the working depth of the plow. Thus, the tractor tests in one given soil condition consisted of eight test runs (four load levels in each selected gear).

About 400 data sets were collected under each load. All curves in the figures were generated by regression in the form of a second order polynomial. Points on the curves represent the second order polynomials for the curve comparisons.

Table (1) : Cone Index Values for Test Fields

Test field	Cone index (kPa)	Soil moisture (%)	soil type
Soft	640	10.3	Sandy loam
Medium	850	14.3	Clay loam
Firm	1280	8.2	Silty loam

Table (2): Weight on Axles under Different Combinations

Axles	All singles & all ballasted (kN)	All dual & nonballasted (kN)	All singles & nonballasted (kN)
Front axle	56.5	53.5	50.0
Rear axle	39.5	36.5	33.0

Tractive Performance

Traactive efficiency was determined and calculated using the following Equation (Wimer and Luth 1974).

$$TE = (1-S)\left[1 - \frac{\frac{1.2}{Cn} + 0.04}{0.75\left(1 - e^{-0.3\,Cn\,S}\right)}\right] \quad (1)$$

where

TE - Tractive efficiency (decimal),

S = Slip ratio (decimal) and,

Cn = Wheel numeric = $\frac{CI.b.d}{W}$

where: CI= soil cone index (kPa),

b = tire unloaded section width (m),

d = tire outer diameter (m),and

W = weight on wheel (kN).

Rolling resistance is defined as the difference between gross traction and drawbar pull. Gross traction is the ratio of drive wheel torque to drive wheel rolling radius where the rolling radius was determined on concrete at zero drawbar pull. All losses due to soil and tire deformation and any other internal resistances of the tractor have been combined into the term motion resistance (ASAE, 1990). One of the more simplified expressions for determining coefficient rolling resistance (CRR) of a wheel was developed by Wismer and Luth (1974) using dimensional analysis:

$$CRR = \frac{1.2}{C_n} + 0.04 \quad (2)$$

where C_n = wheel numeric

The rolling resistance of the tractor (TRR) could be predicted from:

$$TRR = CRR_R . W_R + CRR_F . W_F \quad (3)$$

where:

CRR_R = coefficient of rolling resistance for rear wheel (decimal),

CRR_F = coefficient of rolling resistance for front wheel (decimal),

TRR = total rolling resistance (kN),

W_R = rear wheel weight (kN) and,

W_F = front wheel weight (kN).

$$RRPL(kW) = \frac{TRR.\,V_a}{3.6} \quad (4)$$

where $RRPL$ = power loss due to rolling resistance (kW)

V = tractor speed (km/h)

Power loss due to slip was determined by the following equation:

$$PSL = P\,(V_o - V_a) \quad (5)$$

Where:

PSL power loss due to slip (kW)

P = Drawbar force (kN)

V_o = Speed without load (m/s). and.

V_a = Speed with load (m/s).

Since: Slip ratio (S) determined by the following equation:

$$S = 1 - \frac{V_a}{V_o} \qquad (6)$$

$$\frac{V_a}{V_o} = 1 - S \qquad \therefore V_o = \frac{V_a}{1-S}$$

$$V_o - V_a = \frac{V_a}{1-S} - V_a$$

$$= \frac{V_a - V_a(1-S)}{1-S}$$

$$= V_a \ \frac{1-1+S}{1-S}$$

From Equation (5)

$$PSL = PV_a \frac{S}{1-S} \qquad (7)$$

RESULTS AND DISCUSSIONS

3-1-Tractive performance with fourth gear

In soft soil: The all singles all ballasted combination provided the best tractive efficiency in the draft range up to about 35 kN as shown in Figure (2a). The all singles all nonballasted was the second best following all dual nonballaset ,but in the draft range up to 28 kN, under heavy load, however, the difference in the tractive efficiencies became smaller.

In Tilled Soil: It is interesting to note from Figure (2b) that the all singles nonballasted combination had the highest tractive efficiency in the draft range up to about 30 kN

In Stubble Soil: The stubble soil provided the firmest soil surface for the field tests. Very high tractive efficiency, about 0.78 was observed when the tractor worked with the all dual and nonballasted combination at about 20 kN draft level as shown in Figure (2c).

3-2-Tractive performance with fifth gear:

In soft soil: The tractive performance was much less sensitive to the tire selections and ballast conditions in fifth gear as shown in Figure. (3a). The two ballasted combinations had better tractive performance than the other two combinations in the draft range above 30 kN.

In Tilled Soil: The statistical analysis showed no significant difference in the tractive efficiencies between the all singles with all tires ballasted and the all dual nonballasted combinations (Figure 3b).

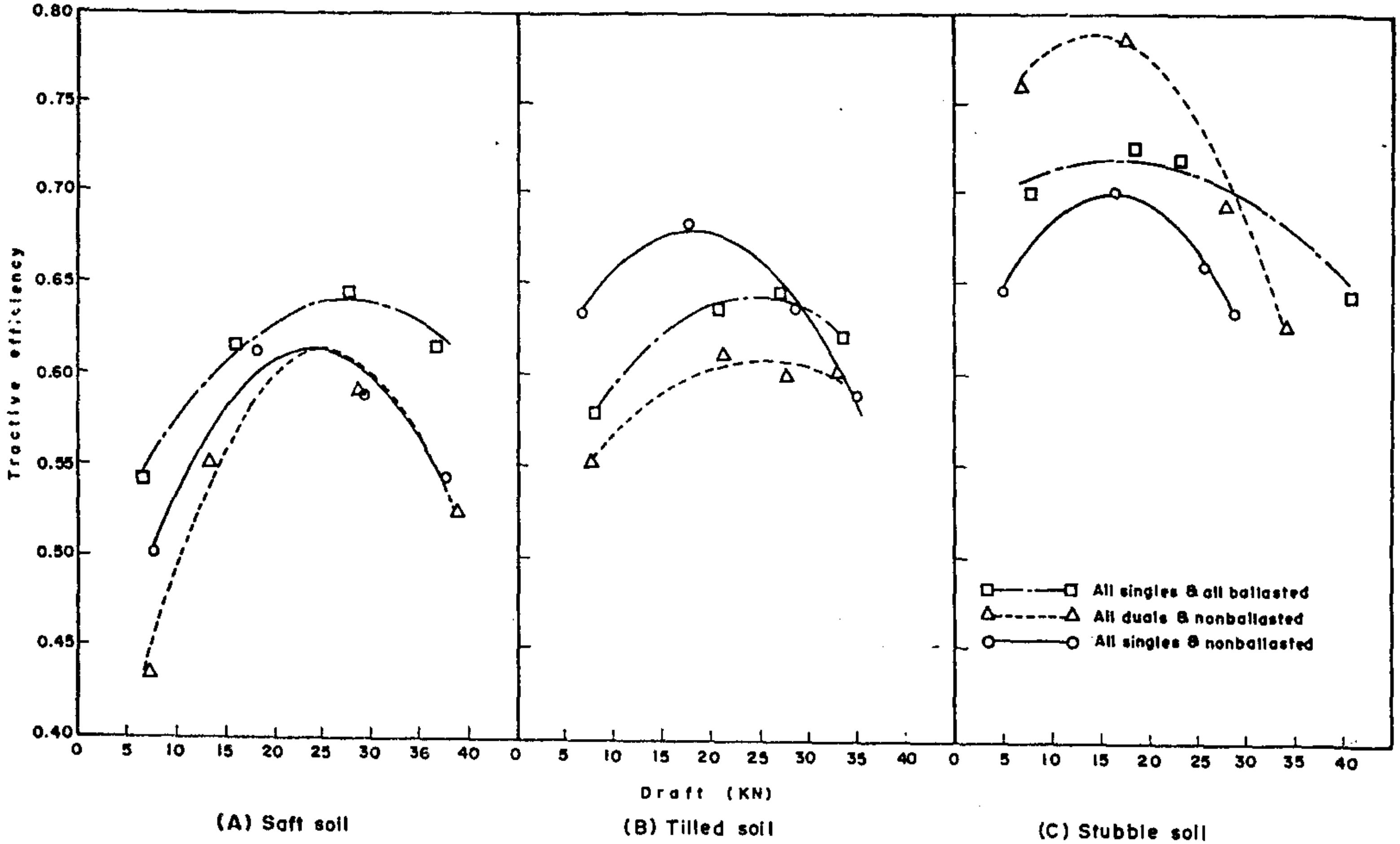

Fig.(2): Tractive efficiency vs. draft in 4th gear in three different soil types .

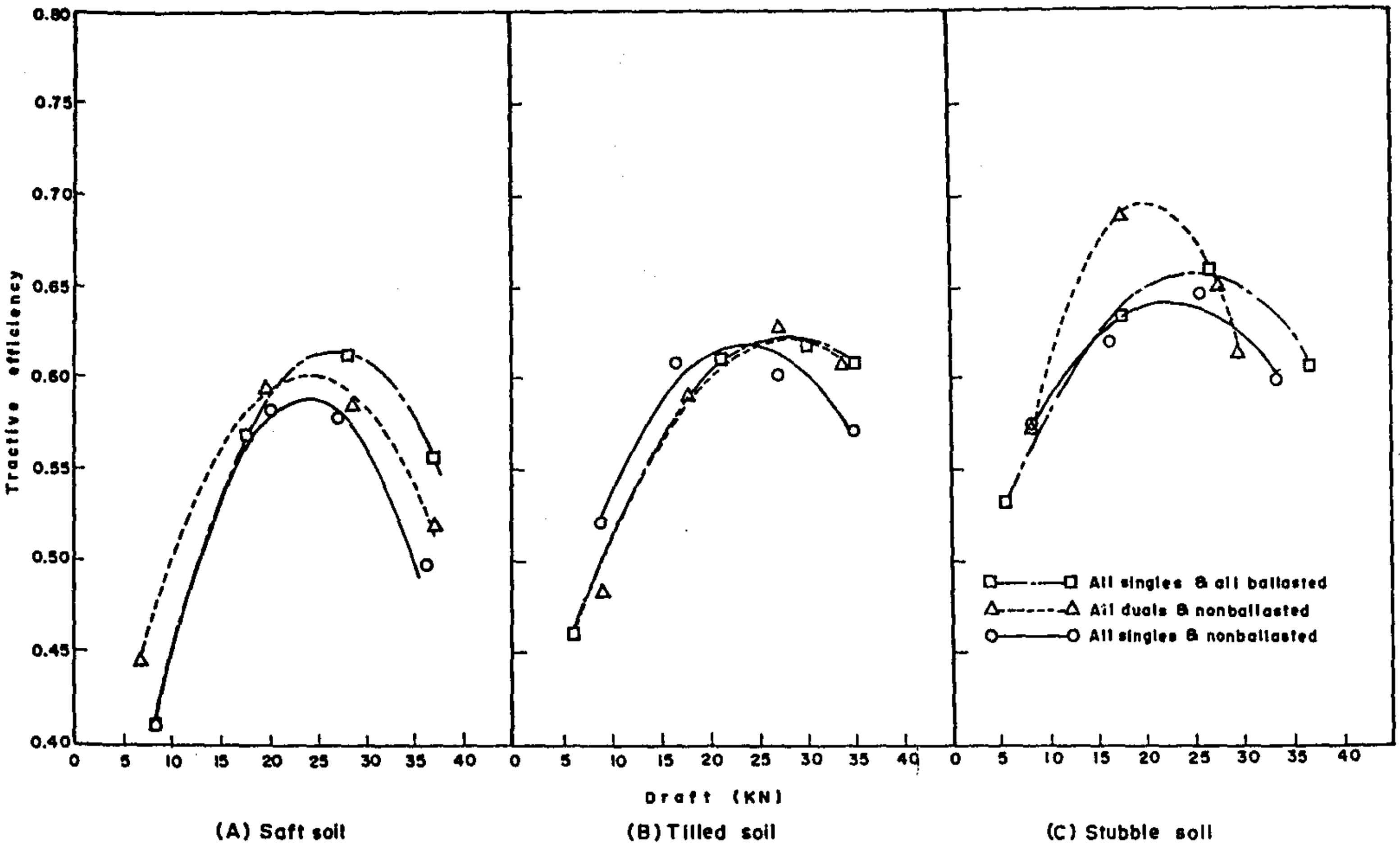

Fig. (3): Tractive efficiency vs. draft in 5th gear in three different soil types .

In Stubble Soil:. The tractive performance of the tractor in fifth gear resembles that in fourth gear except that all the efficiency curves are lower. The tractive efficiency reached a peak value of 0.68 at about 25 kN draft for the all dual nonballasted combination and dropped off sharply afterwards (Figure 3c).

Table (2) indicates how the static weight of the tractor changes with tire selections and ballast conditions. Adding dual wheels to the tractor not only changes the contact area with the soil but also the static weight for any static weight, a maximum tractive efficiency occurred at a certain draft level for all the combinations. In most of the cases, when the static weight increased, the maximum tractive efficiency value occurred at a higher draft value.

Dual wheel or single wheel arrangements may or may not gain traction advantage depending on the soil condition, gear selection and tire ballast. In soft soil in fourth gear, dual wheels with ballast provided the best traction performance in the draft range up to about 35 kN as shown in Figure (2). In tilled soil in fourth gear, dual wheels without ballast had much poorer tractive performance than the two single wheel combinations, while in fifth gear, very similar tractive performance was observed on the dual wheel combination and the single wheels with the ballast combination (Figure 3). In stubble soil, dual wheels without ballast provided good traction performance in the draft range below 30 kN. In both gears, dual wheels with ballast had less satisfactory performance as shown in Figure (2c) and Figure (3c). From the above discussion, dual wheels did not provide good traction performance in most of the cases. This agrees with the tests done by Friesen and Domier (1968). They concluded that, under dry soil conditions, there was no traction advantage obtained in using dual wheels since the cohesive strength of the soil was negligible. All the field tests for this study were considered to have been connected with dry soil conditions, the highest average moisture level was observed in the tilled soil, which was 13.2 percent. It is interesting to notice that the single wheels with ballast provided fairly good traction performance in all three soil conditions in both gears under heavy loads.

3-3- POWER LOSS DUE TO ROLLING RESISTANCE AND SLIP

Power loss percentage was calculated as a ratio between the power loss to the drawbar power. The power loss results are shown in Figures (4 & 5) for two transmission gear settings (fourth gear and fifth gear). Statistical analysis showed no significant difference between the above two combinations in the power losses due to slip as shown in Figure.(4a). The power loss due to rolling resistance for the all singles all ballasted combination was higher than that for the all dual and all ballasted arrangements as shown in Figure (4a). No doubt. the flotation provided by the dual wheels did reduce the rolling resistance and increased the tractive efficiency in softest soil. Poorer tractive performance was observed on the nonballasted combinations.

Figure (4b) shows that, although the power loss due to slip was high for all singles nonballased combinations, the power loss due to the motion resistance was relatively low. The statistical analysis showed no significant difference in the power losses due to the slip for the two dual wheel combinations. As the draft increased, the tractive efficiency dropped sharply for all the singles with nonballasted tire combinations, as shown in Figure (4b) suth that the slip power loss increased rapidly for this combination and the low motion resistance power loss could not compensate for the relatively sharp increase in slip power loss. No doubt, farmers use dual on four-wheel drive tractors in many cases to improve flotation and to reduce soil compaction. Poor tractive performance was observed on the nonballast combinations.

Figure (4c) indicates that the power losses due to both rolling resistance and slip were quite low in the draft range below 30 kN for all dual and nonballasted combinations. Further increase in the draft made the tractive efficiency drop sharply, because of the rapid increase in the power loss due to slip. In contrast to the all singles and all ballasted combination was much less sensitive to the draft change. Single wheels kept the rolling resistance loss relatively low, even in the high draft range as shown in Figure (4c).

3-4 Fuel Consumption

The test data revealed that the gear selections affected the specific fuel consumption (L/drawbar kW.h) of the tractor, as shown in Figure (6). It is obvious from these graphs that it was more economical to operate the tractor in fifth gear. For dual wheel combinations, fifth gear had better fuel performance in the whole draft range, while the advantage in fuel economy was only obtained when the draft was below 35 kN for the two single wheel combinations.

In all three soil conditions, the average value of the maximum tractive efficiency was higher for fourth gear than for fifth gear. On the other hand, the average specific fuel consumption in all soils was lower for fifth gear than for fourth gear. This result agrees with results obtained by Lyne et al. (1982). They found that the maximum tractive efficiency did not necessarily occur at the minimum specific fuel consumption. This phenomenon may be explained by the characteristics of the diesel engine. However, most diesel engines work with higher fuel efficiency at around 80 percent of the rated engine speed. The field data indicated that the operating speed of the engine in fifth gear was always lower than that in terms of fuel efficiency in fifth gear than it did in fourth gear.

CONCLUSIONS

1- The all singles all ballasted outperformed the all dual non ballasted and the all singles non ballasted arrangements in soft soil.
2- Single wheel combinations had better tractive performance than the two dual wheel combinations in medium (tilled) soil except at high drawbar loads.
3- In stubble (firm) soil, no clear advantage occurred for any wheel or ballast combination.
4- No significant differences in specific fuel consumption occurred for the various wheel and ballast combinations. For each combination and for all soils, fifth gear provided better specific fuel consumption than fourth gear.

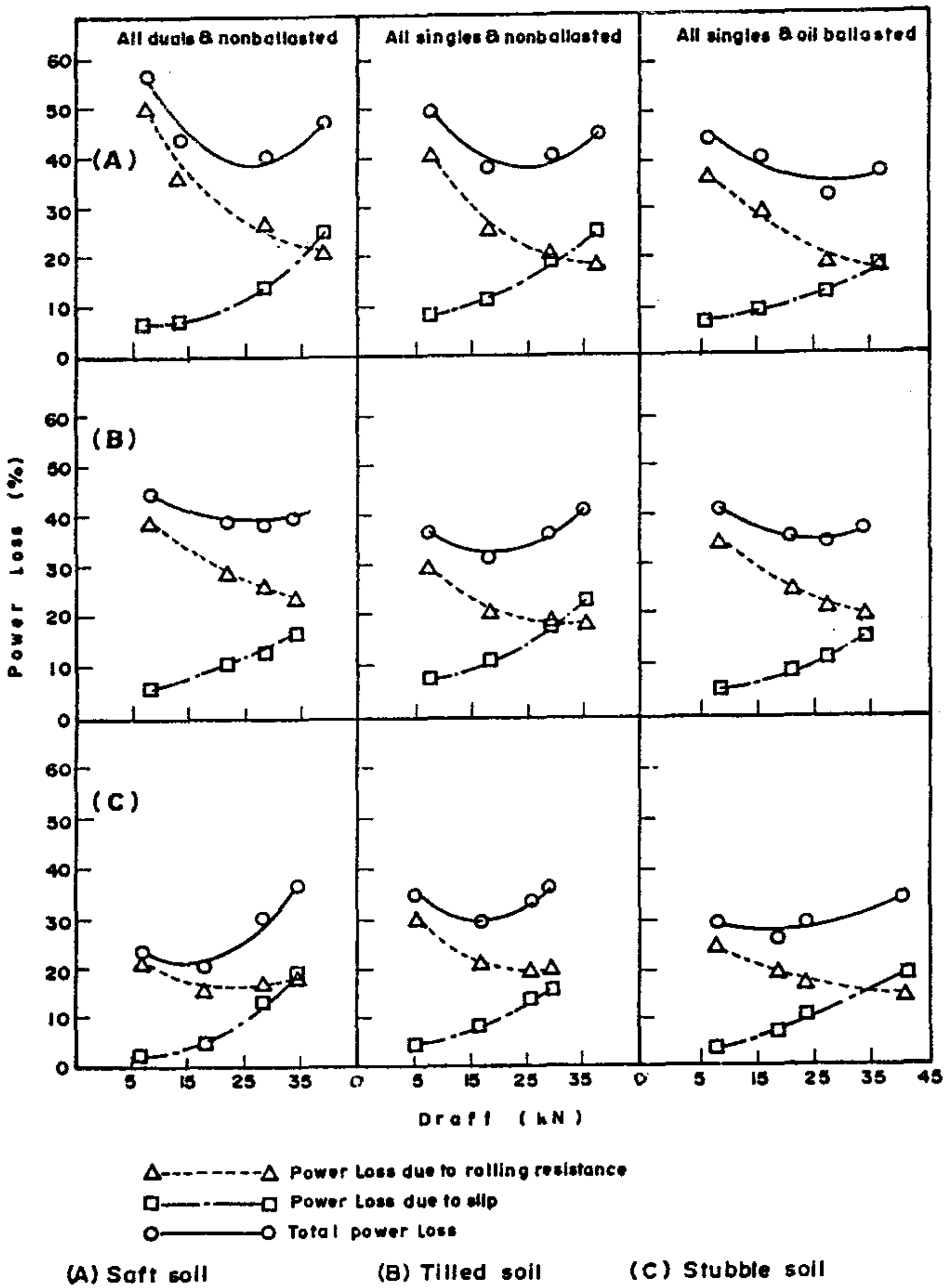

Fig. (4): Power loss vs. draft in 4th gear under different soil types .

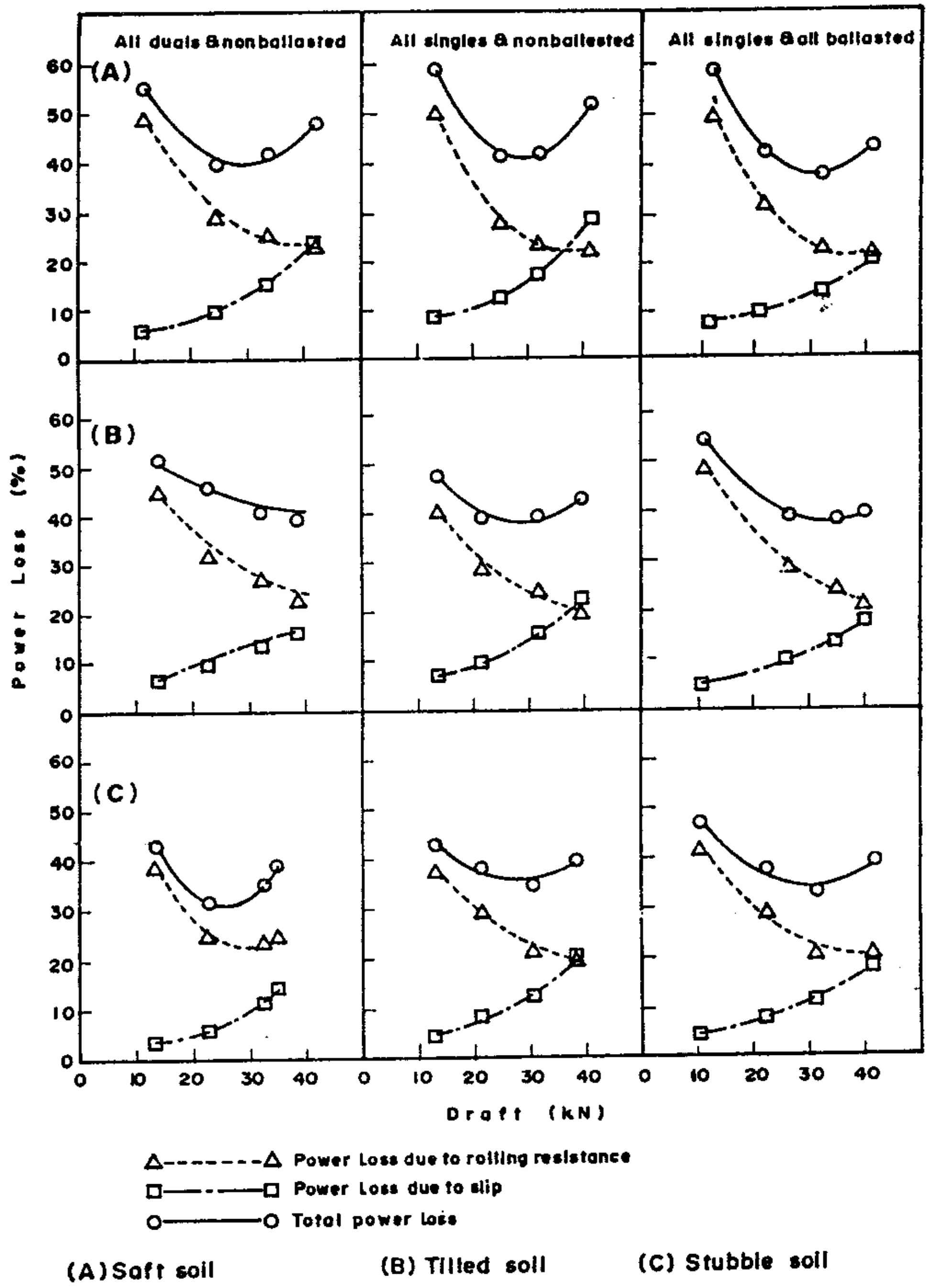

Fig.(5): Power loss vs. draft in 5th gear different soil types .

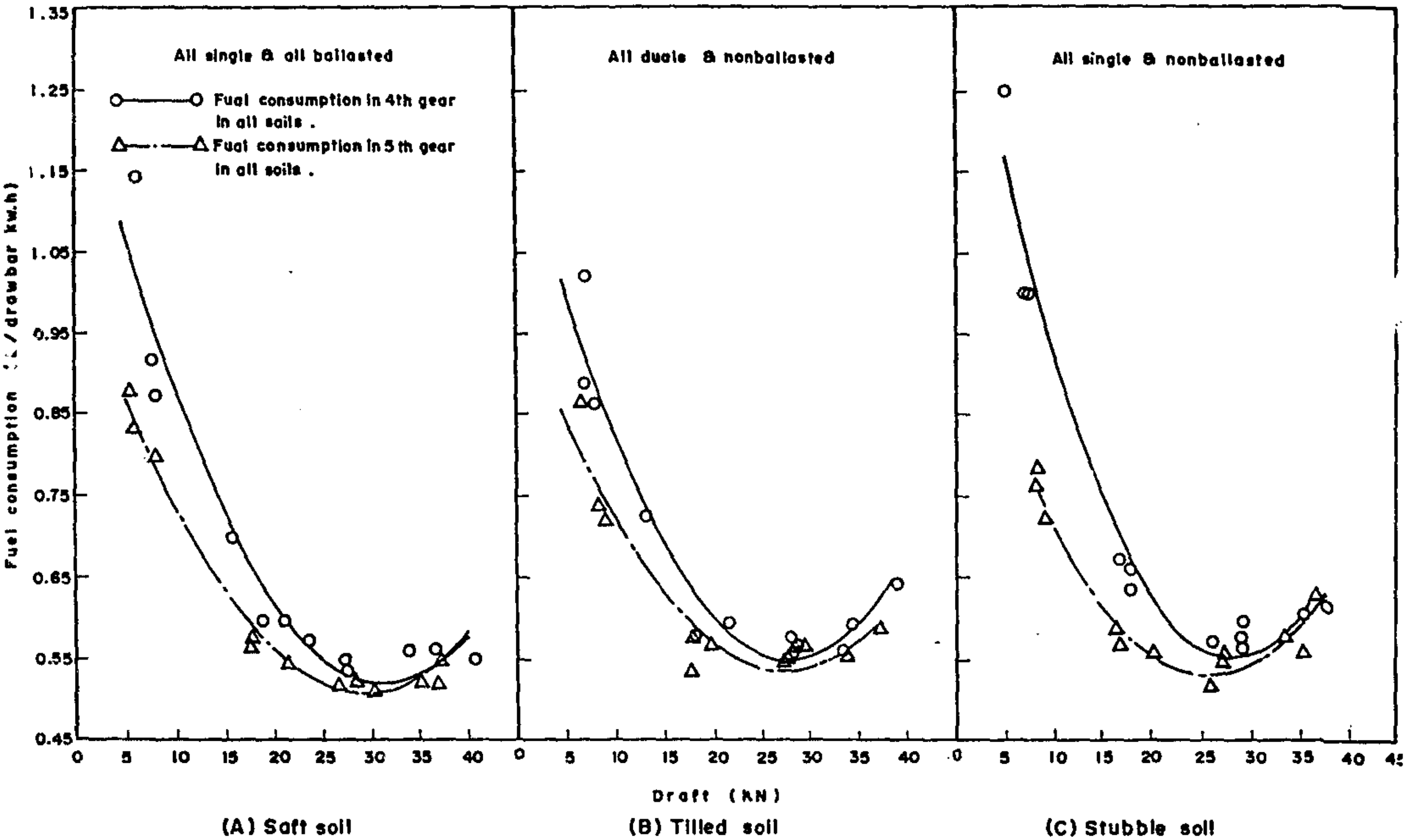

Fig.(6) : Fuel consumption vs. draft .

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الملخص العربى

كفاءة الجر للجرارات رباعية الدفع بتوليفات مختلفة لعدد الإطارات، والأوزان

د/ السعيد رمضان العشرى*

يستهدف البحث دراسة كفاءة الجر واستهلاك الوقود للجرارات رباعية الدفع، وذلك باستخدام ثلاث توليفات من الأوزان والإطارات، تحت ظروف ثلاثة أنواع من التربة، وأوضحت النتائج أن:

استخدام عجل فردى مع أوزان زائدة أعطى تحسنا فى كفاءة الجر عن استخدام العجل الفردى بدون أوزان والعجل الزوجى بدون أوزان فى الأراضى الخفيفة. فى الأراضى المحروثة (متوسطة الصلابة) أعطى العجل الفردى بأوزان وبدون أوزان كفاءة جر أفضل من العجل الزوجى فيما عدا عند الأحمال الكبيرة.

كما أوضحت النتائج أنه لا توجد فروق معنوية فى قيمة الأستهلاك الوقود النوعى للوقود وذلك لجميع المعاملات. وأوضحت النتائج أن الاستهلاك النوعى للوقود أفضل عند استخدام سرعة الترس الخامس بدلاً من سرعة الترس الرابع وذلك لجميع المعاملات.

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