Determination the draft ranges at which 2WD and 4WD tractors operates at their maximum traction efficiency

Shaker H. Aday Sadiq J. Muhsin Salim A. Bander
Machinery dept., Agric. College, Basra University, Basra, Iraq

SUMMARY

This research was conducted on 2WD and 4WD tractors to determine the draft force ranges at which these tractors work at their maximum traction efficiency. Massy –Ferguson tractor of 2WD and 4WD type was used in the experiments. The total weight of the tractor is 48.85kN. The weight acting on the rear and front wheels is 34.63kN and 14.22kN respectively. The rated engine power is 95kW. The experiments were conducted using four tractor forward speeds G_1(0.39), G_2(0.51), G_3(0.72) and G_4(1.20) m/sec and six operating depths (10, 20, 30, 40, 50 and 60cm) for the plow which used to load the tractor engine.

The results showed that the maximum traction efficiency of 2WD and 4WD tractors are 0.72 and 0.79 which occurred at traction wheels slip of 12% and 7% respectively. The draft force range of 4WD was wider than that of 2WD which gives 4WD tractor superiority on 2WD tractor. These draft force ranges are 15-30kN and 12.5-32.5kN and these ranges occurred at wheels slip ranges of 10-30% and 5-19% for 2WD and 4WD tractors respectively. The optimum traction efficiencies (the optimum tractor performance) are 0.78 and 0.85 and they occurred at wheels slip of 17% and 8% and at draft force of 22kN for 2WD and 4WD tractors respectively.

The maximum value of P_F increased as the tractor forward speed increased for both tractors but this maximum P_F provided lower draft force which means the tractor can not pull wider implements or machines working at greater depths but at lower forward speed the situation is better. For lower forward speed (0.39 m/sec) the draft force at which the maximum P_F occurred at is 29 kN and 34 kN for 2WD and 4WD respectively. When the forward speed increased to 1.20 m/sec the draft force decreased to 23kN and 28kN for 2WD and 4WD respectively. The results showed clearly that 4WD surpassed in performance 2WD. it is more efficiently in using the power at the traction wheels as draft force increased with less power losses through the wheels slip and the rolling resistance and that can be seen from the difference between P_d and P_F.

The power at the traction wheels (P_d), the weight of the tractor (G_t) and the tractor forward speed (V_a) were connected in equation for 4WD and

2WD tractors but the weight of the traction wheels (rear wheels) (Z_r) was used for 2WD tractor. Both equations may be used to determine the weight required by the tractor to operate at the maximum traction efficiency.

Keywords: maximum traction efficiency, optimum traction efficiency, draft force range. Draft power, power at the traction wheels

Introduction

The traction ability of any tractor depends on three main factors namely; soil strength, tractor weight and the engine power (1,2,3,4,12,14). The soil strength determines the thrust force generated by the tractor traction wheels, the wheel slip and the rolling resistance on the tractor tires (5,6,9,11). The wheel slip and the rolling resistance are regarded the main sources of power losses in the field (3,8,9,15,19,20). The elements of the soil strength are the soil cohesion and the friction between the soil particles. The cohesion depends upon the clay fraction and the soil moisture content. As the clay fraction increases in the soil and the moisture content decreases or increases beyond a certain limit the cohesion increases considerably. When the soil is at the solid state (dry) the cohesion is high and therefore the soil strength and that resulted in greater thrust force and lower wheel slip and rolling resistance (5,7,10,18). But when the moisture content is high, the soil at the plastic state (wet) the soil cohesion is high but the wheel slip and the rolling resistance is high and that can cause greater power losses and that reduces the tractor traction efficiency. The soil cohesion is utilized by the contact area of the traction tires with soil (2,3,6,17). The soil friction depends on the roughness of the soil particles and that determines by the sand fraction in the soil. The high soil frictions increase the soil strength and positively affect the traction ability of the tractor.The tractor weight effect the tractor traction ability through the friction property of the soil. It increases the interlocking between the soil particles and that increases the soil strength which leads to lower wheel slip. The weight of the tractor is also increases the ability of the tire lugs to penetrate the soil surface and that improves the tire soil grape which can secure soil-soil deformation instead of tire soil deformation (8,13,12,16).

The engine power depends on the design feature of the engine and is almost constant for any tractor but it should be powerful enough to provide the traction wheels with enough power to draw the load (5,6).

Therefore, the soil strength can be utilized efficiently for traction as the tractor weight is greater and the contact area of its traction tires is bigger. Thus the tractor of four wheel drive is preferable because it is full weight and the total area of its traction wheels are used in traction. However, to obtain the highest performance the tractor should be operates at its

maximum traction efficiency and that can be found within a range of draft force. This research was conducted to determine the draft force ranges at which 4WD and 2WD tractors operates at the maximum efficiency and to compare these ranges of both tractor to determine which one gives the wider range. The research also includes studying the draft power and the power at the traction wheels for both tractors.

Materials and methods

The tractor

Massy-Ferguson 2680MF tractor was used in the experiment. It was four wheels drive tractor (4WD) and can be used as two wheels drive tractor (2WD). The total weight of the tractor is 48.85 kN . The weights of the rear and front wheels are 34.63 kN and 14.22 kN respectively. The tractor was provided with Perkins engine of six cylinders. The brake horse power is 95kW. The rear and front tires dimensions are 16.9R38 and 12.4R28 respectively. The tires condition was good.

The experiment parameters

The experiments were carried out in the field using four tractor forward speeds G1 (0.39), G2 (0.51), G3 (0.72) and G4 (1.20) m/sec and six subsoiler operating depths which was used to load the tractor engine to obtain different draft forces and draft powers. These parameters were used for 2WD and 4WD tractors. The parameters used to evaluate the field performance of both tractors are the draft force, the draft power, the power at the traction wheels, the traction efficiency and the wheel slips. The draft force, the wheels slip and the tractor forward speeds were measured in the field while the remaining parameters were calculated from the measured parameters.

The draft force measurement

The draft force of 2WD and 4WD tractors were measured by towing another tractor which a subsoiler plow was attached to it. The draft force was measured by a hydraulic dynamometer which attached to the draw bar of the tractor under test from one end and to a flexible cable from the other end. The flexible cable is attached to the towed tractor. The experiments were conducted by lowering the subsoiler in the soil to one of the operating depths and then the forward speed of the tractor under test was determined by putting the gear box of the tractor in gear. The engine speed of the tractor was fixed at 1500rpm. The tractor then left to move 5m to approach the maximum forward speed then the readings were recorded from the hydraulic dynamometer along a distance of 20 m. each run was repeated three times. This method was conducted for each tractor forward speed and

operating depth and for both tractors. The time required by the tractor to move the distance of 20m was also recorded. The draft force was calculated as follows using the calibration equation of the system:

F= 0.44156X+ 0.80 .....(1)

Where F= the draft force (kN)

X= the reading of the hydraulic dynamometer in bar

The rolling resistance measurement

The rolling resistance of the tested tractor was measured. The tested tractor was pulled by another tractor on the soil surface of the field of the experiments. The rolling resistance was measured by the hydraulic dynamometer in the same method mentioned in section 2.3. The rolling resistance was measured for all the forward speeds used in the research. Each run was repeated three times.

The traction efficiency, the draft force, the draft power, the traction coefficient and the wheels slip

The traction efficiency of the tractor under test is calculated as follows:

$$\eta_t = \frac{F(1-S)}{F+R} \quad \text{.....(2)}$$

Where $\boldsymbol{\eta_t}$ = the traction efficiency.

S= the traction wheels slip.

R= The rolling resistance of the tested tractor (kN)

The wheel slip of the tractor is calculated as follows:

The theoretical velocity of the tractor is calculated for each forward speed of the tractor by:

$$V_t = \frac{D}{t} \quad \text{.....(3)}$$

Where V_t= the theoretical velocity of the tested tractor (m/sec).

D= the distance traveled by the tested tractor (20m) on hard Surface.

t= the time taken by the tractor to move distance of 20m (sec).

The actual forward velocity of the tractor is calculated as follows:

$$V_a = \frac{D}{t} \quad \text{.....(4)}$$

Where V_a= the actual forward velocity of the tested tractor (m/sec).

t= the time taken to move distance of 20m in the field (sec).

The traction wheels slip (%) is calculated as follows:

$$S = \frac{V_t - V_a}{V_t} \quad \text{.....(5)}$$

The draft power is calculated as follows:

$P_F = F * V_a$ .....(6)

Where P_F= the draft power (kW).

The power available at the traction wheels is calculated as follows:

$P_d = H * V_t$ .....(7)

Where P_d= the power available at the traction wheels (kW).

V_t = the theoretical forward speed of the tractor (m/sec).

H= the thrust force (kN)

The tractor thrust can be calculated as follows:

H=F+R .....(8)

The traction coefficients of 2WD and 4WD are calculated in equations (9) and (10) respectively as follows:

$$C_T = \frac{F}{Zr} \quad \text{.....(9)}$$

Where C_T= traction coefficient of the tractor

Zr= the of the tractor acting on the rear wheels (kN)

$$C_T = \frac{F}{G_t} \quad \text{.....(10)}$$

Where G_t= the total weight of the tractor (kN)

Results and Discussions

The traction efficiency of 2WD and 4WD tractors

The traction efficiency represents the ratio of the draft power to the power available at the traction wheels. As the draft power increases the traction efficiency increases and that the aim of the workers on the tractors in the fields. The results showed that the traction of 4WD tractor is higher than that of 2WD tractor. This was because 4WD tractor used its total weight which act on the rear and front wheels while 2WD tractor used the weight which act on its rear wheels only. The weight increases the soil strength underneath the traction wheels of the tractor and this reduces the wheels slip which is the main source of power loss. This can be seen from fig (1) where the traction efficiency of 4WD tractor is higher than that of 2WD tractor for the same wheel slip value. For example when the traction efficiency is 70% for both tractors the wheel slips for this value are 4% and 8% for 4WD and 2WD tractors respectively. However, 2WD tractor achieved this value of traction efficiency at higher value of draft force and that was due to its higher wheels slip.

The traction efficiency increased considerably as the traction wheels slip increased and that was because the increase in the traction efficiency due to the draft power is higher than the decrease in power due to the wheels up to the maximum values of the traction efficiency. The maximum traction efficiencies which represent the maximum performance of both tractors are 0.79 and 0.72 for 4WD and 2WD tractors respectively. These values occurred at wheels slip of 7 % and 12 % respectively.

After the maximum values of the traction efficiency the traction efficiency decreased considerably and that was because the losses in the power due to the wheels slip is higher than the gain in the power due to the draft force.

The traction coefficient of 2WD and 4WD increased considerable between wheels slip of 0 % to 12 % and then the rate of increase is very limited. The traction coefficients values at which the maximum traction efficiencies of 2WD and 4WD occurred are 0.39 and 0.41 respectively.

The relationship between the weight of the traction wheels, the tractor forward speed and the power available at the traction wheels.

The traction efficiency can also be expressed by the following equation:

$$\eta_t = \frac{P_F}{P_d} \qquad \text{.....(11)}$$

Substitute equation (6) in equation (11), then:

$$\eta_t = \frac{F * V_a}{P_d} \qquad \text{.....(12)}$$

When equation (12) is multiplied and divided by Zr for 2WD tractor and G_t for 4WD tractor, the traction efficiencies for 2WD and 4WD can be expressed by equations (13) and (14) respectively.

$$\eta_t = \frac{\frac{F}{Zr} Zr * V_a}{P_d} \qquad \text{.....(13)}$$

$$\eta_t = \frac{\frac{F}{G_t} G_t * V_a}{P_d} \qquad \text{.....(14)}$$

Substitute equations (9) and (10) in equations (13) and (14) respectively.

$$\eta_t = \frac{C_T * Zr * V_a}{P_d} \qquad \text{.....(15)}$$

$$\eta_t = \frac{C_T * G_t * V_a}{P_d} \quad \text{.....(16)}$$

When the values of the traction efficiency (η_t) and traction coefficient (C_T) for 2WD and 4WD which they are 0.72 and 0.39 and 0.79 and 0.41 (obtained from fig1) are substituted in equations (15) and (16) respectively, the traction efficiency is:

$$1.85 = \frac{Zr * V_a}{P_d} \quad \text{.....(17)}$$

$$1.93 = \frac{Zr * V_a}{P_d} \quad \text{.....(18)}$$

Equations (17) and (18) can be rearranged for 2WD and 4WD in equations (19) and (20) respectively.

$$\frac{P_d}{Zr} = \frac{V_a}{1.85} \quad \text{.....(19)}$$

$$\frac{P_d}{G_t} = \frac{V_a}{1.93} \quad \text{.....(20)}$$

Equations (19) and (20) shows that 2WD required less weight on its traction wheels than 4WD tractor because 2WD tractor used the rear wheels only to generate thrust and any excess of weight would increases the rolling resistance which resulted in reducing the traction efficiency. While 4WD used the front and rear wheels thus requires greater weight.
The additional weight decreases as the forward speed increases for both tractors and that is because the wheels deform the soil greatly compared with the low speed which extracts the soil strength for thrust and then for higher traction efficiency and this compensates the added weight.

The relationship between the traction efficiency, the wheels slip and the draft force

The traction efficiencies of 2WD and 4WD increases at reduced rate as the draft force increase to approach the optimum traction efficiency of o.78 and 0.85 for 2WD and 4WD respectively and then decreased (fig 2). The increase occurred because the gain in the draft power due to the increase in the draft force was greater than the reduction in the power due to the wheels slip. After the optimum value the controversy occurred when the traction efficiency decreased. Both optimum values occurred at draft force

of 22kN but at wheels slip of 17% and 8% for 2WD and 4WD respectively which caused the difference between the optimum values.

The draft force ranges at which 2WD and 4WD operates at the maximum traction efficiency can be found from figure (2) by projecting the maximum values of the traction efficiency which were obtained from figure(1) on the traction efficiency-draft force curves of 2WD and 4WD.

From the intersect points A and B on curve 1 and A1 and B1 on curve 2 two lines are drawn vertically to interact the draft force axis at C and D and C1 and D1 for 2WD and 4Wd tractors respectively. Therefore, the draft force ranges which exist between these points are 15-30kN and 12.5-32.5kN for 2WD and 4WD respectively. The wheels slip at which these draft force ranges occurred within are 10-30% and 5-19% for 2WD and 4WD respectively. This means 4WD operates at wider range of draft force within the maximum traction efficiency and this is regarded advantage for this tractor on the 2WD tractor. This was because the power loss of 4WD due to the wheels slip is lower than that for 2WD as it can be seen from the ranges of the wheels slip and that was related to the greater weight of 4WD which increased the soil strength underneath the traction wheels.

The results indicate clearly that the field performance of 4WD tractor is superior to 2WD tractor and that was because it uses its total weight which enables the traction wheels to utilize the soil strength (soil friction) to greater extent. And it has greater contact area because it uses four tires which utilized the soil cohesion. The weight and the contact area increase the thrust generated by the tractor and reduce the wheels slip.

The relationship between the draft power and the power at the traction wheels and the draft force

This relationship shows the ability of the tractor to converts the power available at the traction wheels to draft power and the power wasted in the rolling resistance and the wheels slip as well as the power at the traction wheels which the tractor can not converted to draft power because the soil strength limitation.

In general, the draft power increased as the draft force increased for all the tractor forward speeds and for 2WD and 4WD, figures (3) and (4). At the slowest tractor forward speed (0.39 m/sec) the draft power declined at draft force of 28kN and 34kN for 2WD and 4WD respectively. This was because the soil approached its maximum strength which leads to soil deformation underneath the wheels which resulted in sever wheels slip. But the superiority of 4WD on 2WD tractor was because 4WD tractor used its total weight in contrast of 2WD tractor and that increased the soil strength underneath its wheels which increased the ability of the tractor to convert more power available at its traction wheels to draft power and then to draft

force. The difference between P_{d1} and P_{F1} is related to the power losses by the rolling resistance and the wheels slip and the difference between them increased as the draft force increased and that was because the wheels slip increased with forward speed.

When the tractor forward speed increased to (1.20 m/sec), the draft force at which P_{d4} occurred at decreased for both tractors. For 2WD and 4WD the draft force is 23kN and 28kN respectively. The reduction in draft force is because the effect of the weight on the soil strength decreased because the wheels do not have enough time to compact the soil as well as the tires cheering the soil due to the high speed.

The difference between P_{F1} and P_{F4} for the same draft force is a power consumed for the forward speed of the tractor. P_{d2}, P_{d3}, P_{F2} and P_{F3} are medium between P_{d1}, P_{d4}, P_{F1} and P_{F4}.

The power available at the traction wheels at engine speed of 1500rpm is 59.5kN but both tractors could not utilized it because the soil strength limitation. This power could be used if the soil strength was high and the draft force requirement by the load is high.

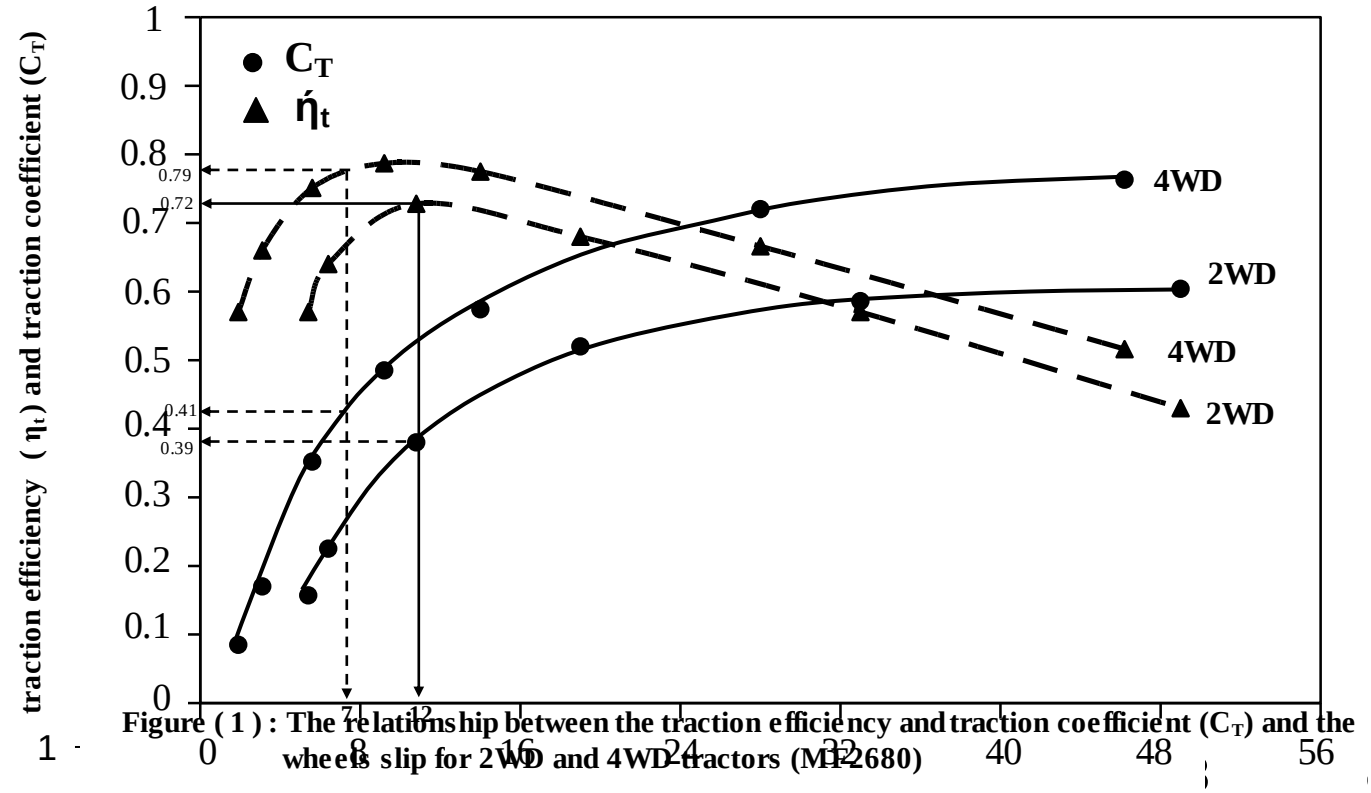


Figure (1) : The relationship between the traction efficiency and traction coefficient (C_T) and the wheels slip for 2WD and 4WD tractors (MF2680)

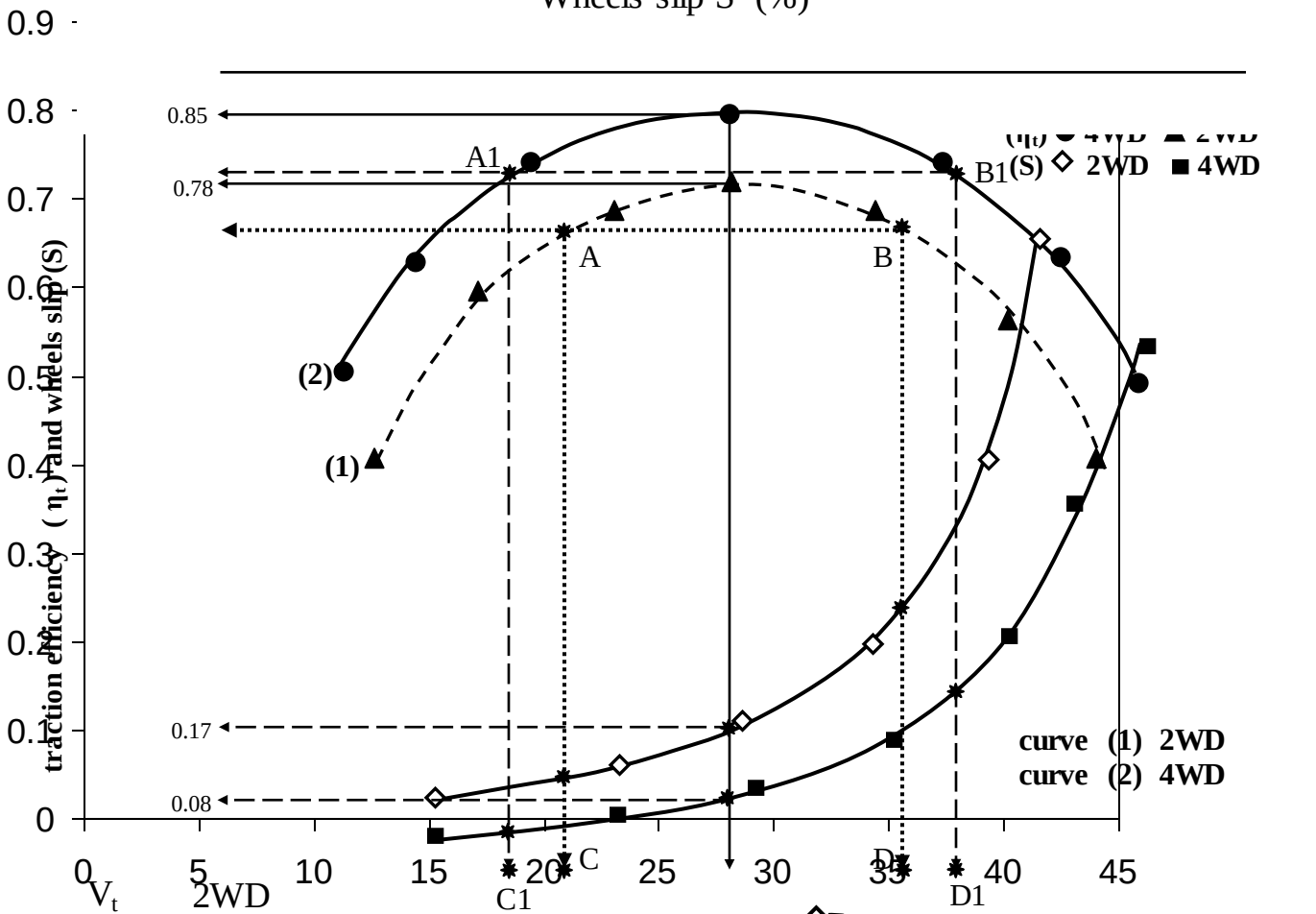
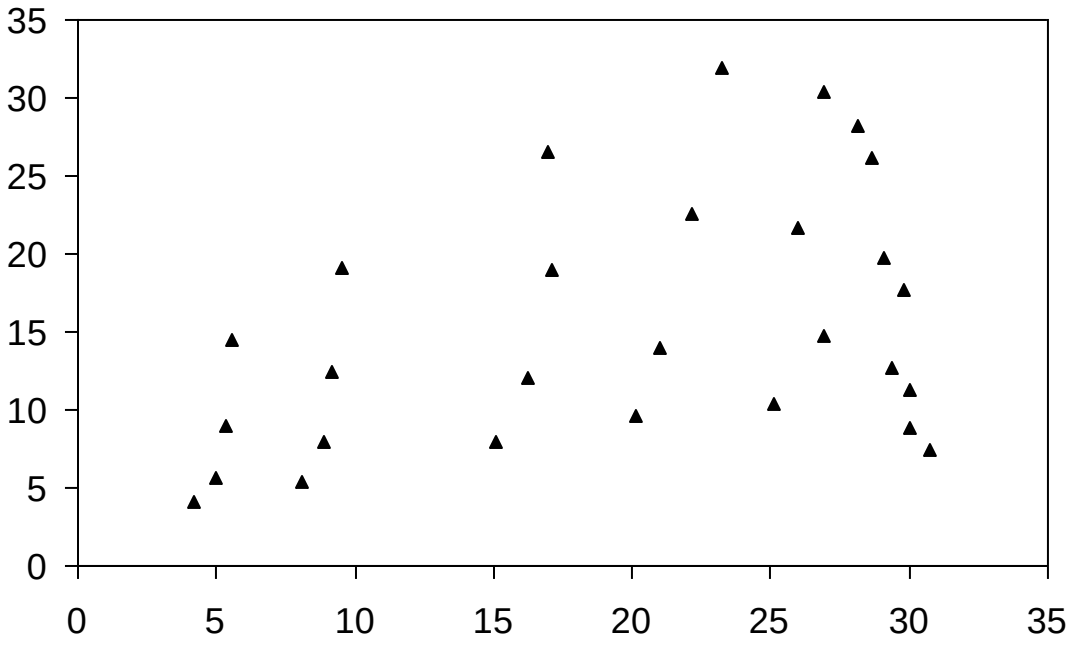


Figure (2) : The relationship between the traction efficiency (η_t) and wheels slip (S) and the draft force (F) for 2WD and 4WD tractors (MF2680).


35
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35


45
40
35
V_t 4WD
0.39 P_{F1} P_{d1}
0.51 P_{F2} P_{d2}
0.72 P_{F3} P_{d3}
(P_F and P_d) kW

Conclusions

(1) The traction efficiency of 4WD tractor (0.79)is higher than that of 2WD (0.72) and these two values occurred at wheels slip 7% and 13% respectively.
(2) The optimum traction efficiency for 2WD and 4WD is 0.79 and 0.85 and they occurred at wheels slip 17% and 8% and at draft force 22kN respectively.
(3) The draft force ranges which 2WD and 4WD tractors operates at the maximum traction efficiency are 15-30kN and 12.5-32.5kN and wheels slip ranges are 10-30% and 7-19% respectively.
(4) The maximum draft power for 2WD and 4WD tractors increased as the forward speed increased but the draft force which is corresponding to the maximum draft power decreased and that reduced the tractor performance

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تحديد مدى قوة السحب التي تعمل ضمنها الجرارات 2WD و 4WD عند كفاءة السحب القصوى

شاكر حنتوش عداي صادق جبار محسن سالم عجر بندر
قسم المكائن والآلات الزراعية / كلية الزراعة / جامعة البصرة / البصرة / العراق

الخلاصة

اجر هذا البحث لتحديد مدى قوة السحب التي تعمل ضمنها الجرارات التي تولد دفع بعجلاتها ألخلفيه 2WD والتي تولد دفع بعجلاتها الخلفية والأمامية 4WD عند كفاءة السحب القصوى . استخدم الجرار ماسي فركسن (2680) من نوع 4WD . وزنه الكلي (48.85 kN) والوزن الذي تحمله العجلات الخلفية (34.63 kN) والأمامية (14.22 kN) ، قدرة المحرك التصميمية عند الدولاب الطيار 95 kW . نفذت التجربة باستخدام أربع سرع أمامية هي (G1 (0.39 و (0.51)G2 و (0.72)G3 و (1.20)G4 m/sec وستة أعماق حراثه باستخدام محراث تحت سطح التربة لتحميل الجرار للحصول على قوة سحب مختلفة . أظهرت النتائج أن كفاءة السحب القصوى للجرارين 2WD و 4WD هي 0.72 و 0.79 ويقعان عند انزلاق 12% و 7% على التوالي . ومدى قوة السحب التي يعمل ضمنها الجرارين عند كفاءة السحب القصوى هي 15-30kN و 12.5-32.5kN وهذين المديين يقعان عند مدى الانزلاق 10-30 % و 5-19 % على التوالي، وهذين المديين يوضحان تفوق الجرار 4WD على الجرار 2WD . اما كفاءتي السحب المثاليتين للجرارين 2WD و 4WD هي 0.78 و 0.85 وهذين القمتين تقعان عند انزلاق 17 % و 8 % وعند قوة سحب 22 kN على التوالي. اما قدرة السحب القصوى زادت مع زيادة السرعة الأمامية للجرارين إلا أن قوة السحب التي تقع عندها قيم قدرة السحب القصوى قلت مع السرعة الأمامية وهذا يعني انخفاض قابلية الجرار على السحب ، فعند السرعة البطيئة (0.39 m/sec) G1 كانت قوة السحب 29kN و 34kN

وعند زيادة السرعة الأمامية إلى (1.20 m/sec)G4 انخفضت قوة السحب إلـــى 23kN و 28kN للجرارين 2WD و 4WD على التوالي. إما بالنسبة للسرعتين G2 و G3 كانت قيم قوة السحب وسط للقيم أعلاه . كما أظهرت النتائج تفوق الجرار 4WD على الجـــرار 2WD حيث كانت كفاءة سحبه أعلى والفقد بالقدرة بالانزلاق ومقاومة التدحرج على إطاراته اقل .

تم ربط القدرة عند عجلات الدفع والوزن المؤثر على هـــذه العجـــلات والســـرعه الامامـــة للجرارين 2WD و 4WD بمعادلتين لحساب الوزن المطلوب على عجـــلات الـــدفع لجعـــل الجرارين يعملان عند كفاءة السحب القصوى. من المعادلتين يلاحظ ان الجرار النى يولد دفـــع بعجلاتة الخلفية فقط يحتاج الى وزن اقل من الجرار الى يولد دفع بعجلاتة الامامية والخلفيـــة لكون الاخير يوزع الوزن على عجلاتة الاربعة. كما يلاحظ من المعادلتين أنخفـــاض الـــوزن المطلوب عند زيادة السرعه الاماميه ولكلا الجرارين وذلك لان جزئ من القدرة المتوفرة عنـــد عجلات الدفع يذهب للسرعة الامامية ويبقى جزئ أقل للدفع والذي يحتاج الى وزن أقل لتحويلها الى قدرة سحب.