Evaluation of the tractor draft power and power losses at different engine and forward speeds in different soil conditions

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Evaluation of the tractor draft power and power losses at different engine and forward speeds in different soil conditions

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Abstract

Two-wheel drive tractor (Antor 80) was used to conduct this work. The tractor was provided with engine of 58kW. The experiments were conducted to study the ability of the tractor to convert the power available at its traction wheels to draft power and the traction wheels power losses. The parameters of the experiments were four engine speeds (1250, 1500, 1750 and 2000 rpm), four forward speeds (G_1, G_2, G_3 and G_4) and three soil types.

The results showed that the ability of the tractor to convert the power available at its traction wheels to draft power increased as the tractor forward and engine speeds increased. The power at the driving wheels increased from 11 to 44 kW when the forward speed increased from G1 to G_4. However, the values of the draft force which corresponding to the maximum value of the draft power decreased as the forward speed increased while the engine speed had limit effect on the draft force. The maximum draft force range was 22 to 17 kN for lower and higher forward speed respectively. However, despite of increase in the draft power with forward speed but the draft force decreased appreciably. Thus to prevent tractor engine from coming standstill either the implement operating depth or width must be decreased.

The power losses increased as the forward speed increased and as the soil hardness decreased. The losses in power were 2.8 and 5.5 kN in hard and friable soils respectively, while it was medium in the semi-hard soil.

1.0 Introduction

The tractors are mainly used for pulling the implements in the fields, thus, the draft power which the tractor can provided is the main factor in determining the implement depth and width and in some cases the implement type (Aday 1997 and Dwyer 1984). The draft force depends on many factors among them are the power available at the traction wheels which is determined by the engine power and the transmission efficiency, as the engine power and the transmission efficiency were higher as the power available at the driving wheels was higher.

The ability of the tractor to convert the power available at the traction wheels to draft power depends on the soil strength and the forward speed. The soil strength is the decisive factor in determining the thrust force and therefore the draft force as well as the rolling resistance (draft force = thrust force – rolling resistance) (Bekker 1969, Dwyer 1984, Aday 1997 and Al-.-Maliki 2000). The rolling resistance increases as the soil strength decreases because the weakness of the soil strength causes high wheel sinkage. The soil strength affect the wheels slip considerably, it increases as the soil strength decreases. The rolling resistance and the wheel slip are the main sources of power losses so when they were low the draft force was high.

The high forward speed of the tractor increases the tractor power utilization ability which available at the traction wheels. However, the forward speed should be within a certain limit otherwise it increases the power requirement for tractor and implement acceleration and that reduces the power for traction.

The soil strength can be expressed by cone index which is used to calculate the mobility number. The mobility number represents the ability of the tractor to move on the soil surface.

Freitage (1965) expressed the mobility number for clay and sand soils by Eqs.1 and 2 using the cone index (the force required to push the penetrometer in the soil divided by the cone base area).

$$N_C = \frac{C.b.d}{W}\sqrt{\frac{\delta}{h}} \qquad \text{............(1)}$$

$$N_S = \frac{C(b \cdot d)^{\frac{3}{2}}}{W}\sqrt{\frac{\delta}{h}} \qquad \text{..............(2)}$$

Where:

N_C=mobility number of the clay soil.

N_S= mobility number of the sand soil.

C= Cone index (kN/m^2).

G= gradient of the relationship between cone index and depth.

δ= tire deflection (m)

h= tire section height (m)

b= tire width (m)

d= tire diameter (m)

However, Turnage (1972) developed Eq. 1 by adding the shape of the contact area of the tire therefore, Eq. 1 became as follows:

$$N_C = \frac{C.b.d}{W}\sqrt{\frac{\delta}{h}}\frac{1}{1+\frac{d}{2d}} \qquad \text{............(3)}$$

Wismer and Luth (1973) developed a mobility number for the cohesive-frictional soils and they called it "wheel numeric" Eq. 4

$$N_{CS} = \frac{C.b.d}{W} \qquad \text{.............(4)}$$

3.0 Materials and methods

3.1 The tractor under test

Zetor (8001) tractor (Antor 80) was used to conduct the experiments. The tractor was provided with four cylinders diesel engine. The engine stroke and the cylinder bore were 120 and 110 mm respectively. The compression ratio was 17:1. The engine nominal power was 58kW. The transmission systems efficiency was 83%. The tractor of 2WD type. The rear tires size was 38-14/16.9. the height of the tire lugs were 2cm and their inclination angle with center line of the tire was 45^0. The tractor was provided with gear box of eight forward speeds, four low (low gear ratios) and four high speed (high gear ratios).

3.2 Subsoiler

A subsoiler was used to conducted the experiments. It consisted of single tine. The forward angle of the subsoiler was 67^0. The attack angle of its foot was 30^0. The subsoiler was used at operating depth of 10, 15, 20, 25, 35, 45 and 50cm to obtained different tractor draft forces.

Table (1): Soil physical and mechanical properties

Operating Depth (cm)	Hard soil			Semi-hard soil			Friable soil		
	Moist. Content %	Bulk Density kg/m^3	Cone index kN/m^2	Moist. Content %	Bulk Density kg/m^3	Cone Index kN/m^2	Moist. Content %	Bulk Density kg/m^3	Cone index kN/m^2
0-10	9.3	1458	3115	18.2	1287	1713	23.8	1266	914
10-20	13.2	1449	3893	20.6	1213	1437	26.7	1150	1495
20-30	16.6	1417	3166	22.8	1336	2961	24.7	1367	2803
30-40	24.8	1272	2219	30.1	1246	2230	30.6	1240	2118
40-50	29.3	1161	1619	34.3	1133	1824	33.3	1140	1869

4.1 Soil parameters measurement

The moisture content was measured across experimental field. The soil samples were taken by cores. The moisture content was calculated by weighing method. The soil bulk density was measured using the core method (Black et al 1965). The results are shown in table (1). The soil cohesion and angle of internal friction were measured by annulus ring method (Gill and Vanden berg). The results are shown in table (2).

Table (2): the mechanical properties of the soil

<table>
<tr><th rowspan="2">Soil type</th><th rowspan="2">Cohesion kN/m^2</th><th rowspan="2">Angle of internal friction Φ^0</th><th colspan="3">Soil texture</th></tr>
<tr><th>sand</th><th>silt</th><th>clay</th></tr>
<tr><td>Hard</td><td>0.48</td><td>40.1</td><td rowspan="3">4.2</td><td rowspan="3">44.2</td><td rowspan="3">51.6</td></tr>
<tr><td>Semi-hard</td><td>7.13</td><td>36.6</td></tr>
<tr><td>Friable</td><td>6.83</td><td>34.4</td></tr>
</table>

4.2 the tractor theoretical forward speeds

the theoretical forward speeds of the tractor were measured on a hard and leveled road. Four forward speeds were chosen for each engine speeds. The forward speeds were G_1, G_2, G_3 and G_4. The engine speeds were 1250, 1500, 1750 and 2000rpm.

The engine speed of the tractor was fixed on one of the previously mentioned speeds. The gear box of the tractor was put in gear one of the four forward speeds(e.g G_1). The tractor then left to move 3m forward to approach the maximum forward speed. The time to move the distance equal to two revaluations of its rear tires was taken. The distance was 13.85 m. The theoretical forward speed was calculated by dividing the distance (13.85m) by the time measured. Each run was repeated three times. The results are shown in table (3).

Table (3): the tractor theoretical forward speed (m/sec)

Engine speeds (rpm) / Forward speeds	1250	1500	1750	2000
G_1	0.426	0.49	0.57	0.65
G_2	0.646	0.77	0.88	0.99
G_3	1.02	1.20	1.42	1.61
G_4	1.49	1.68	2.03	2.18

4.3 The draft force and the actual forward speed measurement

The subsoiler was attached to MF tractor. MF tractor - subsoiler combination were towed by the tractor under test (Antor 80). A hydraulic dynamometer to measure the draft force was attached to Antor 80 tractor drawbar pull from one side and to flexible cable from the other side. The other end of the flexible cable was attached to the MF tractor- subsoiler combination.

The subsoiler depth was predetermined using one of the operating depths of the experiments (10, 20, 30, 40 and 50cm). The engine speed of the tractor under test was fixed on one of the speeds under test (1250, 1500, 1750 and 2000 rpm) and its gear box was put in gear (G1, G2, G3 and G_4). Then it was left to move distance of 3m to approach the maximum forward speed. MF tractor gear box was left in neutral. The readings were recorded from the hydraulic dynamometer and the time taken to move distance of 13.85m (two revolutions of the traction wheels) was also recorded. The measurements were taken for all the operating depths, forward speeds, engine speeds and soil types.

The draft force was calculated using the calibration equation of the dynamometer, Eq. (5).

$$F=0.8+0.44156X \qquad \ldots\ldots\ldots\ldots\ldots(5)$$

Where F= The draft force (kN)

X= The dynamometer reading (bar)

The actual forward speed was calculated by Eq. (6).

$$V_a = \frac{X_a}{t} \qquad \text{…………..(6)}$$

Where: V_a= The actual forward speed (m/sec).

X_a= The distance traveled by the tractor (13.85m)

T= time taken to move the above distance

4.4 The rolling resistance

The rolling resistance of the tractor under test was measured in the field also. Four forward speeds were used to carry out the experiments (G_1, G_2, G_3 and G_4). The rolling resistance was measured in the three soil types, hard, semi-hard and friable soils. The measurements were conducted by towing the tractor under test by another tractor. The readings were recorded for all forward and engine speeds. Each run was repeated three times. The rolling resistance was calculated using Eq. 5.

2.7 the draft power and the power available at traction wheels

The draft power was calculated by Eq. 7

$$P_F = F \cdot V_a \qquad \text{…………….(7)}$$

Where: P_F= The draft power (kW)

F= the draft force (kN)

V_a= the actual forward speed (m/sec)

The power at the traction wheels was calculated by Eq. 8.

$$P_d = \frac{P_F}{\eta_t} \qquad \text{…………….(8)}$$

Where: P_d= The power at the traction wheels (kW)

η_t= traction efficiency

The traction efficiency of the tractor under test was calculated by Eq. 9

$$\eta_t = \frac{F(1-S)}{F+R} \qquad \text{.............(9)}$$

Where: S= traction wheels slip (%)

R= rolling resistance (kN)

Wheels slip was calculated by Eq. (10)

$$S = \frac{V_t - V_a}{V_t} \qquad \text{................(10)}$$

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

5.0 Results and Discussion

5.1 The relationship between the draft power and the power at the traction wheels and the draft force for different forward speeds

The draft power (P_F) and the power at the driving wheels (P_d) increased as the draft force increased for the four forward speeds up to a certain value and then both of them declined. However, the value at which P_F and P_d decreased depended on the tractor forward speed. For lower engine speed 1250 rpm and slower forward speed (G_1) both powers decreased at draft force (F) of 22kN, Fig.1. This reduction in P_F and P_d at this value of F was related to either the tractor used the total power available at the traction wheels which engine speed of 1250rpm produced or the soil strength under the traction tires approached its maximum value and then the soil deformed excessively which reduced the tractor forward speed and the draft force which both reduced P_F and P_d.

For the second forward speed (G_2), P_F and P_d were higher in values than that for (G_1), However, the maximum values occurred at lower draft force and that was because part of the power available at the traction wheels was spent to accelerate the tractor and another part was dissipated in the wheels slip which increased with the forward speed. The maximum values of P_F and P_d occurred at F of 20 kN. However, the power losses due to the wheels slip increased considerably due to the increase in thrust generated by the traction wheels to supply extra power to accelerate the tractor and to pull the subsoiler. The same trend can be seen with third and fourth gear (G_3 and G_4), P_F and P_d increased. The maximum values of P_F and P_d occurred at F values of 19 and 17kN for G_3 and G_4 respectively.

Increasing engine speed to 1500 rpm, Fig. 2, PF increased with F and then decreased when F exceeded 24 kN, however, P_d was not consumed by the tractor completely as the straight line of P_d indicated. This meant part of the power available at the driving wheels of the tractor could not be used because the thrust force exceeded the soil strength which caused considerable wheel slip. However, F value was higher than that for $G_1$of engine speed of 1250 rpm. When G_1 increased to G_2, F at which the maximum value of P_F occurred at was 22kN. In this case Pd was consumed completely by the tractor and this meant that tractor power was limited rather than soil strength weakness. The soil strength withstood 24 kN before it deformed as the previous results inducted (G_1 and 1500 rpm). This means to prevent the tractor engine stoppage, F should be less than 22 kN. For G_3 and G_4, the maximum values of P_F occurred at F values of 21 and 20 respectively. For G3 and G4, Pd was consumed completely according to their curves.

When the engine speed was increased to 1750 rpm, F which the maximum value of P_F occurred at remained almost the same for that of engine speed of 1500 rpm, Fig. 3. F values were 24, 22, 20 and 19 kN for G1, G2, G_3 and G_4 respectively. At this engine speed, P_d was consumed completely as it can be seen from their curves for G_2, G_3 and G_4 only.

The ability of the tractor to convert P_d to P_F improved considerable with the forward speed of the tractor. For example at G_1, 11 kW from P_d was converted, 9 kW as P_F and 2kW was dissipated as power losses in overcoming the rolling resistance and wasted in the wheels slip. Increasing the forward speed from G_1 to G_4, the tractor converted 31kW as P_F from Pd of 43kW. The difference between the values of P_d and P_F (12 kW) represented the power lost at the traction wheels. These values of P_d and P_F occurred at F of 20 kN. This means the tractor used the power available at its wheels of traction better than when its forward speed was low, the power was available but it was not used. This results inducted that the forward speed should be selected to spare enough power for traction.

For engine speed of 2000 rpm, F value at which the maximum P_F occurred at remained almost the same for engine speed of 1750 rpm, Fig. 4. The results should that the tractor could not consumed P_d completely with G_1 despite of its increase due to the engine speed (2000 rpm). However, there was slight increase in P_d consumption when G_1 increased to G_4 compared with its values with engine speed of 1750 rpm. The consumed Pd was 11.5 and 44 kW with G_1 and G_4 while P_F values which coincided with these two values were 8 and 33 kW. The difference between the values of P_d and P_F represented the power losses in the traction wheels.

3.2 The relationship between the draft power and the power available at the traction wheels and the draft force for three soil types

P_F for the hard soil was higher than for the other two soil types for the same value of F. This could be related to the low power losses whether by the wheels slip or the rolling resistance in this soil type, Fig 5. P_F for the semi-hard soil was higher than that for the friable soil and that was due to the high power losses by the wheels slip and the rolling resistance and that was because the soil surface weakness.

Maximum values of P_F were 12.5, 11 and 8 kW for hard, semi-hard and friable soils respectively. These values occurred at F values of 22.5, 18 and 17.5 kN respectively. These values indicated that the tractor cannot pull any implement requires higher draft power than the above values in such soil types.

Pd in the semi-hard and friable soils was not consumed completely while it was consumed in the hard soil. The reason was the soil strength of the semi-hard and friable soils was weak so that they were deformed excessively under the traction wheels and great amount of power was dissipated in wheel slip.

5.2 the relationship between the power losses and the mobility number

Fig. 6 illustrates the power losses (P_L) at the traction wheels of the tractor versus the mobility number (M) for three forward speeds G_1, G_2 and G_3. P_L decreased considerably as M increased. This was related to the increase in the soil hardness expressed by higher M. Soil hardness on other hand means less wheel slip and lower rolling resistance which both are the main sources of power losses in the field.

The results showed that P_L increased appreciably as the forward speed increased for the same M. For example, when M was 70, P_L were 2.5, 3.8 and 5.5 kW for G_1, G_2 and G_3 respectively. The reason was that the high forward speed increased F which on the other hand increased the thrust generated by the traction wheels. The high thrust caused severe soil deformation which accomplished by high wheel slip.

Conclusions

The following conclusions were drawn from this research.

(1) The ability of the tractor in converting the power available at its traction wheels to draft power increased as the forward speed increased.

(2) The maximum draft force which corresponding to the maximum draft power decreased as the forward speed increased. The draft force rang was 17 to 22 kN for higher and lower forward speeds respectively.

(3) At the higher forward speeds the soil strength was the limit factor to convert the power available at the traction wheels to draft power whereas at higher soil strength the power available at the traction wheels was the limit factor.

(4) At low forward speed the implement operating depth and width can be increased but at higher forward speed contrary is true.

(5) At higher engine speed both the power available at the traction wheels and the draft force increased.

(6) The power losses at the tractor driving wheels increased with the forward speed and with the soil strength weakness. The losses range was between 3 to 12 kW for lower and higher forward speeds.

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تقييم قدرة السحب والقدرة عند اطارات دفع الجرارات التي تولد دفع بإطاراتها الخلفية والفقد في القدرة عند الاطارات لسرع محرك ولسرع أمامية مختلفة في ثلاثة أنوع من الترب

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الخلاصة

أجري هذا البحث على جرار يولد دفع بإطاراته الخلفية (عنتر 80) لتقيم قدرته على السحب والقدرة المتوفرة عند اطارته الخلفية والفقد بالقدرة عند هذه الاطارات في ثلاثة انواع من الترب وهي الصلبة وشبه الصلبة والهشة.

نفذت التجارب باستخدام اربع سرع محرك 1250 و 1500 و 1750 و 2000 دورة/دقيقة واربع سرع امامية مع كل سرعة للمحرك G_1 و G_2 و G_3 و G_4 و وخمسة اعماق للمحراث الذي يسحبه الجرار لتحميل المحرك 10 و20 و 30 و 40 و 50 سم وثلاثة انواع من الترب (صلبة وشبه صلبة وهشة).

أظهرت النتائج زيادة قابلية الجرار على تحويل القدرة عند الاطارات الى قدرة سحب كلما زادت السرعة الامامية وبصورة محدودة مع زيادة سرعة المحرك.

زادت القدرة المستغلة عن اطارات الدفع من 11 الى kN44 عند زيادة سرعة المحرك من G_1 الى G_4. وانخفضت قوة السحب القصوى التي تقع عند قدرة السحب القصوى كلما زادت السرعة الامامية لهذا عند زيادة السرعة الامامية يجب تقليل عمق المحراث أو عرضة لتوفير القدرة اللازمة لسحبة لمنع احتمالية توقف محرك الجرار. تراوحت قوة السحب بين 22 الى 17 kN للسرع الامامية المنخفضة والعالية على التوالي ولسرع المحرك الاربعة. للحصول على قوة سحب عالية يجب استخدام الجرار عند سرع المحرك المتوسطة (1500-1750 دورة/دقيقة) والسرعة الامامية البطيئة لأن سرع المحرك العالية تعطي سرع أمامية عالية واستخدام السرع الامامية العالية عند ثبوت سرعة المحرك تستهلك جزء كبير من القدرة بالتعجيل وانزلاق اطارات الدفع ومقاومة التدحرج.

عند السرع البطيئة بعض الأحيان لم تستخدم القدرة المتوفرة عند الاطارات بأكملها بسبب ضعف قوة التربة والتي تسبب انزلاق عالي الذي يستنزف الكثير من القدرة.

زاد الفقد بالقدرة مع زيادة السرعة الامامية والذي تراوح بين 3 الى 12 kW للسرع الامامية البطيئة والعالية على التوالي. ويزداد هذا الفقد بزيادة سرعة المحرك لأنها تسبب زيادة السرعة الامامية. كما أن الفقد بالقدرة في التربة الهشة اعلى منة في التربة شبه صلبة وفي الاخيرة اعلى منة في التربة الصلبة. وبسبب انخفاض الفقد في التربة الصلبة فان القدرة المتوفرة للسحب اعلى منها في الترب الاخرى.

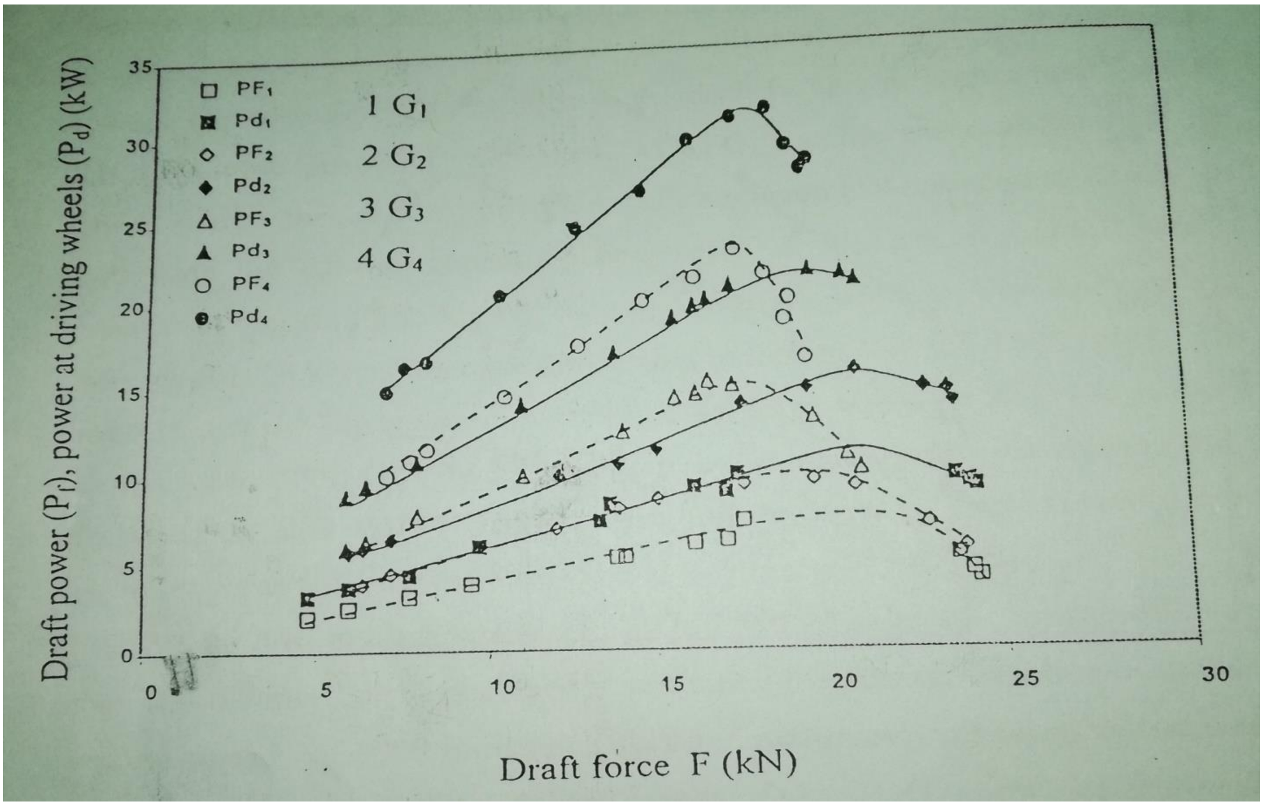

Fig. 1: The draft power and the power at the driving wheels versus draft force for four forward speeds and engine speed of 1250 rpm

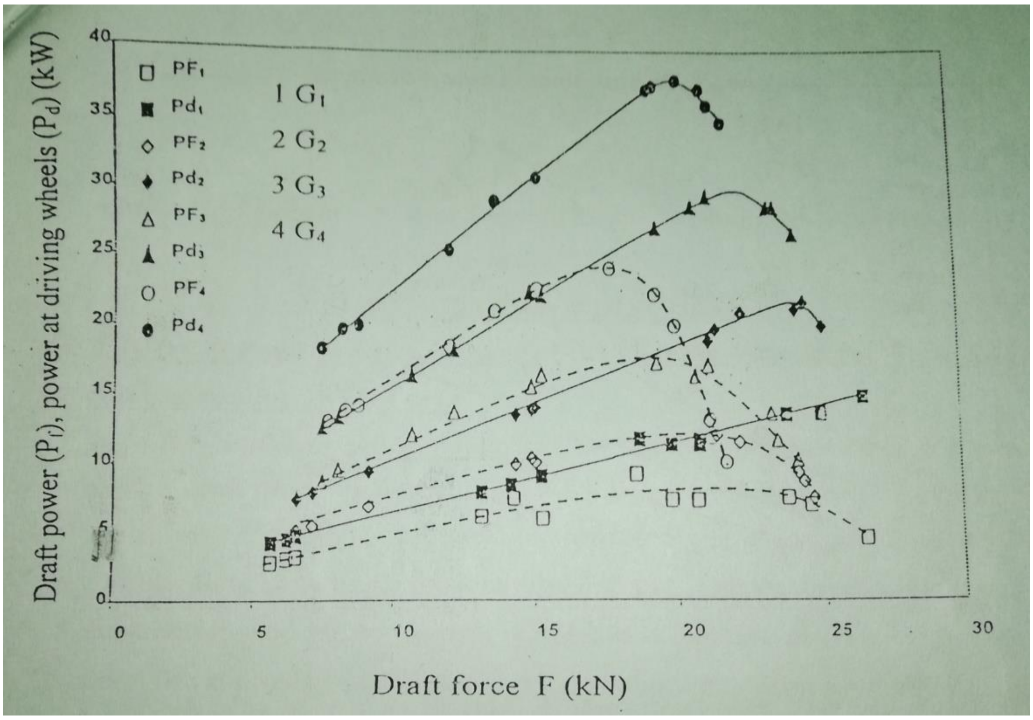

Fig. 2: The draft power and the power available at the driving wheels versus draft force for four forward speeds and engine speed of 1500 rpm

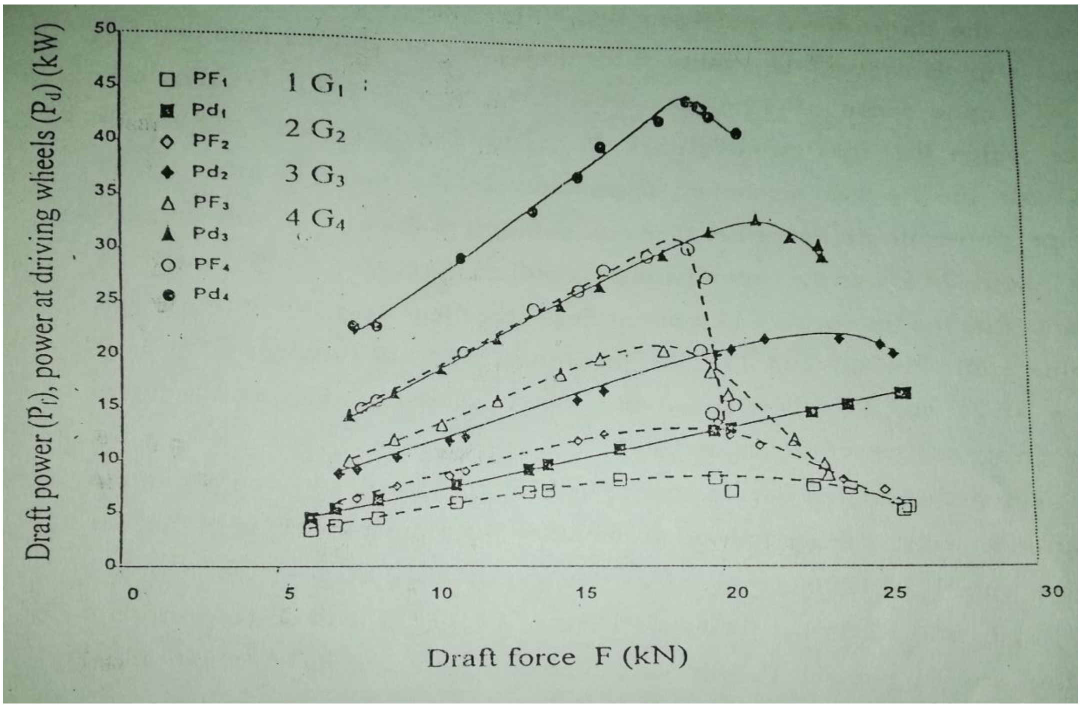

Fig. 3: The draft power and power at the driving wheels versus draft force for four forward speed and engine speed of 1750 rpm.

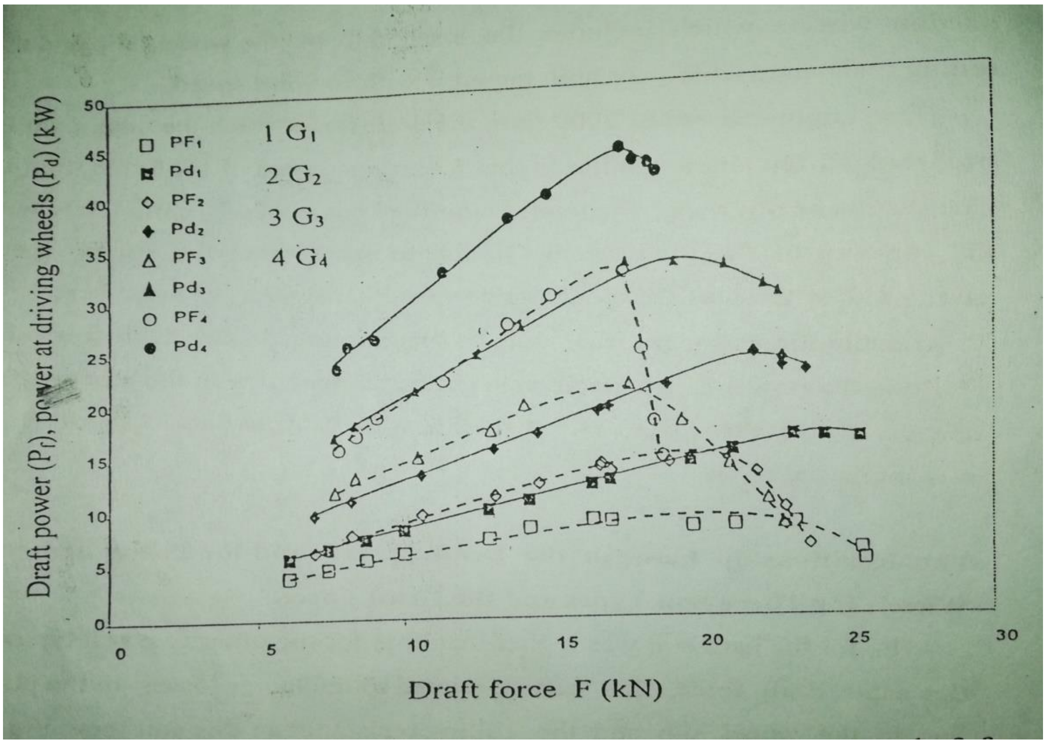

Fig. 4: The draft power and and the power available at the driving wheels versus draft force for four speeds and engine speed of 2000 rpm.

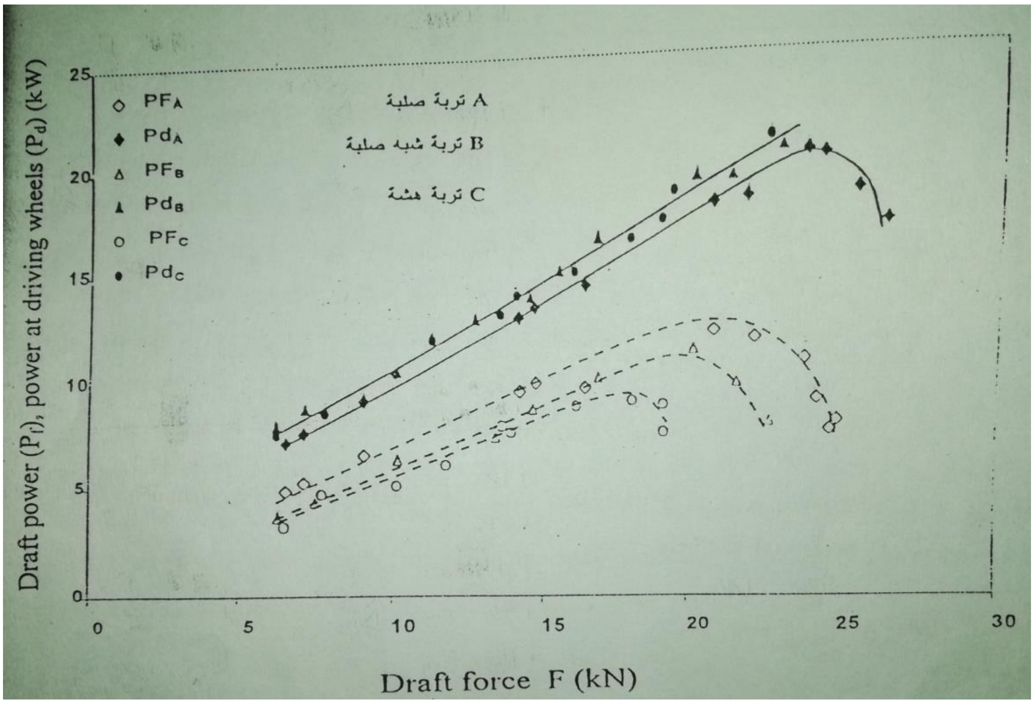

Fig. 5: The draft power and he power at the driving wheels versus draft force for three soil types.

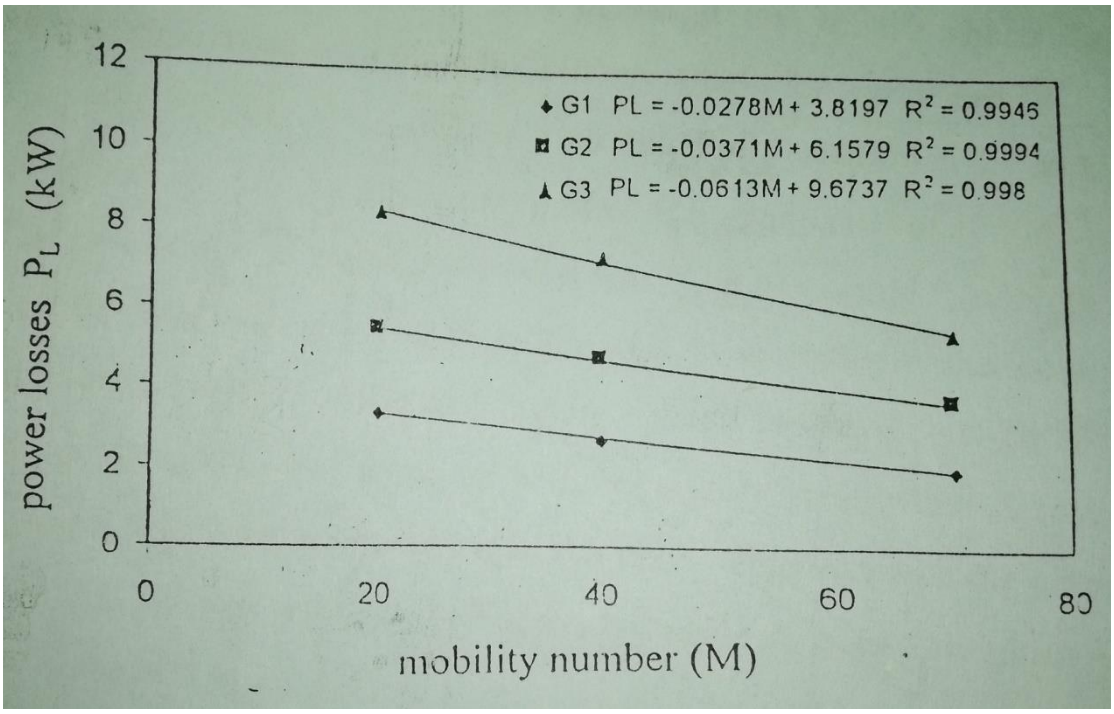

Fig. 6: power losses at driving wheels versus mobility number for three forward speeds