

## TRACTOR FUEL CONSUMPTION PER UNIT AREA AS RELATED TO TRACTOR ENGINE SPEED, FORWARD SPEED AND PLOWING DEPTH

S. H Aday\*      S. A. Najim\*\*      M. S. Hmood\*

### ABSTRACT

Fuel consumption per unit area ( $F_a$ ) which means the number of kilograms or liters of fuel required to plow an area of hectare ( $10000m^2$ ) or donum ( $2500m^2$ ) of soil is widely used as parameter to evaluate the fuel consumption in the field in order to determine the quantity of the fuel required to plow a certain area of soil and hence the cost of the required fuel.

To evaluate this parameter, Zetor tractor (6901), was used to carry out the experiments. The tractor was provided with four cylinders engine. The engine stroke and cylinder bore are 110 and 102mm respectively. Engine compression ratio is 17:1 and the fuel injection pump was of in-line type. The experiment parameters used to carry out the tests were engine speeds of 1250,1500,1750 and 2000rpm, forward speeds of  $G_{3h}$ ,  $G_{4h}$ ,  $G_{1L}$  and  $G_{5h}$  (four forward speeds for each engine speed) and three plowing depths (10,15 and 20 cm) to load the tractor engine.

Results showed that the engine speed of 1500 rpm gave the lowest fuel consumption per unit area ( $F_a$ ), i.e. as  $F_a$  is lower as the tractor performance is better, less fuel consumption per unit area, while the engine speed of 1750rpm became second. The highest engine speed (2000rpm) had lower  $F_a$  than the lowest engine speed (1250 rpm), thereupon the tractor should be used at higher engine speed rather than lower speed for greater fuel saving and therefore lower cost. The highest tractor forward speed for each engine speed and shallow plowing depth (10cm) gave the lowest  $F_a$ . The addition of 300kg to the tractor driving wheels improved the fuel consumption per unit area; it reduced  $F_a$  further for all engine speeds, tractor forward speeds and plowing depth. However, the lowest  $F_a$  (9.5kg/ha) was recorded with engine speed of 1500rpm, highest forward speed (0.85 m/sec), this forward speed was obtained with engine speed of 1500rpm and gear ratio of  $G_{5h}$ , plowing depth 10cm and the added weight of 300kg. This combination of parameters would save about 61% from the total fuel consumption and cost requirement of plowing one hectare compared with the combination parameters of the slowest engine speed (1250 rpm), lowest forward speed (0.32 m/sec), deepest plowing depth and without addition of 300kg to the tractor driving wheels.

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Received:Dec./2002

Accepted:Sept./2006

## INTRODUCTION

The fuel consumption per unit area ( $F_a$ ) (kg/ha) is a parameter widely used to determine the fuel consumption to plow a certain area of land (hectare=10000m<sup>2</sup> or denim=2500m<sup>2</sup>). The fuel consumption per unit area depends on the tractor engine characteristics such as engine speed, compression ratio, engine stroke and cylinder bore (1,3 and 6). In addition, the tractor forward speed and the implement width parameters are both regarded as the most effective parameters on  $F_a$  (2,8). The higher tractor forward speed and wider implement width produce a greater plowed area in a unit time and they lowered fuel consumption compared with slower forward speed and narrower implement width. The engine speed and the plowing depth have a limited effect on  $F_a$  compared with previous parameters; their effect on  $F_a$  is through the tractor forward speed. The soil type, however, has an indirect effect on  $F_a$ , in the hard and wet heavy soils the draft force of the tractor is high causing sever tractor wheel slip, which resulted in lower tractor forward speed and therefore, smaller plowed area which resulted in higher  $F_a$  (4).

This work was conducted to study the effect of the tractor forward speeds, the tractor engine speeds, the plowing depths and the added weight to the tractor driving wheels on  $F_a$  and to determine the best combination of the previous factors that gives the lowest  $F_a$  and lowest fuel cost.

The experiments were conducted using four engine speeds 1250,1500,1750 and 2000rpm, four tractor forward speeds (four gear ratios)  $G_{3h}$ ,  $G_{4h}$ ,  $G_{1L}$  and  $G_{5h}$ , three plowing depths 10, 15 and 20cm and weight of 300kg was added to the tractor rear wheels (traction wheels).

## MATERIALS AND METHODS

### Zetor tractor 6901

Zetor tractor 6901 is used in this work. The tractor is provided with diesel engine of four cylinders and four strokes. The stroke and bore are 110 and 102mm respectively. Engine compression ratio is 17:1. The fuel injection pump is of In-line type. The brake power of the engine is 48kW (64.5hp) at engine speed of 2200rpm. The tractor box is of sliding type which can give five slow and five high forward speeds. The tractor total weight is 26.2kN (2730kg). The rear and the front wheels carry weight of 17.26kN (760kg) and 9.51kN (970kg) respectively. The rear and the front wheels provided with extra weight of 3.09kN (315kg) and 1.5kN (160kg) respectively. The size of the rear and the front wheels are 16/14-28 and 16-7.50 respectively.

### Moldboard plow

A moldboard plow of three bodies was used to conduct the experiments. The bodies are of deep-digger type. The working width of the plow is 1.05m. The plow was not provided with skim coulters.

### The fuel consumption measurement system

The system consists of a fuel tank with three liters capacity, valve and a graduated cylinder (Figure1). The valve was fixed at its base and connected to the graduated cylinder by plastic tube. The cylinder capacity

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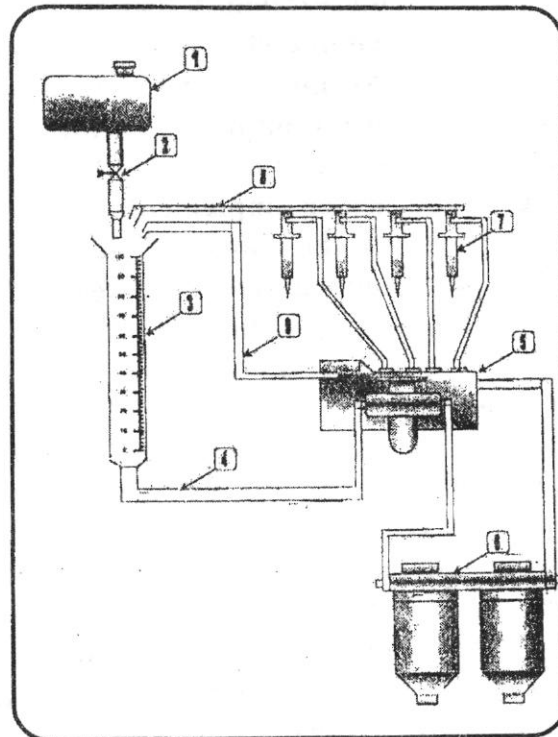
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Tractor fuel consumption per ...

is 100 ml and its end connected to the tractor fuel injection pump by plastic tube. The pipes of the excess fuel from the injection pump and the injector are connected to the graduated cylinder at the upper end.



- 1- Fuel tank 2- Valve 3- graduated cylinder 4- Plastic tube  
5- Fuel injection pump 6- Filter 7- Injectors  
8- Tube of excess fuel from injectors  
9- Tube of excess fuel from injection pump.

Figure 1: Fuel measurement system.

### The tractor theoretical forward speed

The tractor theoretical forward speeds were measured on a hard level road. The forward speeds were  $G_{3h}$ ,  $G_{4h}$ ,  $G_{1L}$  and  $G_{5h}$ . These forward speeds were measured for each engine speeds, which are 1250, 1500, 1750 and 2000rpm. The engine speed of the tractor was fixed on one of the selected speeds using the hand control lever. The tractor gear box was engaged on one of the chosen gears. The tractor was then left to move a distance of 5m to approach the top forward speed and then another 15m. Two marks were used at the beginning and the end of the 15m distance. The time taken to move the distance of 15 m was recorded. The measurements were repeated three times for each forward speed. The forward speed was calculated as follows:

$$Vt = \frac{Dt}{t}$$

Where:  $Vt$ = theoretical forward speed (m/sec)

$Dt$ = distance moved by the tractor (15m0)

$t$  = time taken to move  $Dt$  (sec)

The tractor forward speeds are shown in table (1).

Table1: theoretical forward speeds of the tractor under test on a hard surface

Engine speeds (rpm) \ Forward speeds (m/sec)	1250	1500	1750	2000
G <sub>3h</sub>	0.32	0.35	0.41	0.46
G <sub>4h</sub>	0.42	0.55	0.63	0.70
G <sub>1L</sub>	0.58	0.71	0.90	1.00
G <sub>5h</sub>	0.74	0.88	1.03	1.17

The measurements of tractor fuel consumption and actual forward speed

The moldboard plow was attached to MF tractor (Massy Ferguson). MF tractor-moldboard plow combination was towed by the Zetor tractor. A hydraulic dynamometer for measuring the draft force of the tractor was attached to the drawbar of the Zetor tractor. A flexible cable was attached to the far end of the hydraulic dynamometer and to the front of the MF-moldboard plow combination. The experiments were conducted by fixing the tractor engine speed on one of the speeds chosen in the experiments (ex. 1250rpm) then the gear of the towing tractor (Zetor) was engaged on one of the gears that mentioned previously. The moldboard plow was lowered down using the MF tractors hydraulic system and the Zetor tractor was left to move forward to let the plow penetrate the soil to the one of the plowing depth chosen to fulfill the experiments (i.e. 10cm). The Zetor tractor was left to move 5m forward to approach the maximum forward speed. The measurements, which includes the draft force of the tractor, the time taken to move the distance of 15m and the fuel consumption were taken by putting a sign on the land at the beginning and the end of the distance of 15m. The fuel consumption was recorded by reading the fuel level in the graduated cylinder at the beginning and the end of the distance of 15m. The fuel consumed to move this distance is the difference between the two levels recorded from the cylinder.

The actual forward speed of the tractor in the field was calculated by the following equation:

$$V_a = \frac{D_a}{t}$$

where:  $V_a$ = the tractor actual forward speed (m/sec)

$D_a$ = the distance moved by the Zetor tractor (15m)

$t$ = the time taken to move the distance of 15m.

The fuel consumption per hour (h) can be calculated as follows:

$$F_h = \frac{F_m}{t} * 3.6$$

Where:  $F_h$ = fuel consumption (kg/h)

$F_m$ = fuel consumed in moving 15m (kg/t)

## Tractor fuel consumption per ...

The fuel consumption (kg/h) calculation was carried out as follows:

The fuel consumed in moving distance of 15m in one of the runs carried out in the field was 39g and the time was 40 sec,  $F_h$  is;

$$F_h = \frac{30}{40} \times \frac{3600}{1000} = \frac{3}{4} \times 3.6 = 2.7 \text{ kg/h}$$

## The site description

The experiments were carried out in silty clay soil. The soil surface was quiet level and cover with small size and numbers of plant. The plants had very limit effect on the tractor traction ability.

## Soil measurements

Soil moisture content, soil bulk density, soil cohesion, angle of internal friction and soil penetration resistance were measured a cross the area of the experiments. Soil moisture content and bulk density were measured by the core method as described by (5). The annulus ring apparatus was used to measure the soil cohesion and the angle of internal friction (7). The penetration resistance of the soil was measured by hydraulic penetrometer expressed by the cone index. The cone index is the ratio of the soil penetration resistance divided by the cone base of the hydraulic penetrometer. The results are shown in table (2).

Table (2): Soil physical and mechanical properties for different depths

Depths (cm)	Cone index (kN/m <sup>2</sup> )	Bulk density (t/m <sup>3</sup> )	Moisture content (%)	Cohesion (kN/m <sup>2</sup> )	Angle of internal friction (degrees)	Soil particles size distribution	Soil texture
0-10	4902.7	1.37	18.2	10.6	28.4	Sand silt clay (g/kg) 141 411 448	Silty clay
10-15	5397.4	1.32	20.1				
15-20	5986.2	1.38	21.7				

## Fuel consumption per unit area

The fuel consumption per unit area can be calculated as follows:

$$F_a = \frac{F_h}{V_i \times B_i} \times 2.78$$

where:  $F_a$  = Fuel consumption per unit area (kg/ha)

$V_i$  = tractor actual forward speed (m/sec)

$B_i$  = implement width (m)

## RESULTS AND DISCUSSION

### Engine speed

$F_a$  decreased as the engine speed of the tractor increased to approach the lowest value of 15.58kg/ha at engine speed of 1500rpm and thereafter increased when engine speed was increased further (Figure 2). The low  $F_a$  with engine speed of 1500rpm compared with that of engine

speed of 1250rpm despite of the lower fuel consumption of the later engine speed was because the tractor forward speed with engine speed of 1500rpm was higher than that with engine speed of 1250rpm which increased the plowed area per unit time resulted in lower  $F_a$ . This means the high tractor forward speed produced by engine speed of 1500rpm overcame the advantage of the low fuel consumption of the engine speed of 1250. However, the advantage of the engine speed of 1500rpm in giving lower  $F_a$  compared with that of engine speeds of 1750 and 2000rpm is related to: firstly, the lower fuel consumption of engine speed of 1500rpm. secondly, the tractor forward speed with engine speeds 1750 and 2000rpm was not high enough due to the high tractor wheels slip which accomplished these two engine speeds to overcome the advantage of lower fuel consumption of engine speed of 1500rpm.

The results also revealed that  $F_a$  of both engine speeds 1750 and 2000 rpm was lower than that for engine speed of 1250rpm despite of their high fuel consumption requirement. The domination of both engine speeds in producing lower  $F_a$  was due to the higher forward speed of the tractor compared with that of engine speed of 1250rpm which omitted the effect of the lower fuel consumption of engine speed of 1250rpm. This means the high forward speed had greater effect on  $F_a$  than the fuel consumption. Therefore to reduce  $F_a$ , the tractor should be work in higher forward speed.

#### Forward speed

$F_a$  decreased considerably as the tractor forward speed increased (Figure 3), for example, when the tractor forward speed increased from 0.38 to 0.85 m/sec  $F_a$  decreased by 9.49kg/ha. However, the high forward speed should be within a limit to leave enough power for the tractor to pull the implement, otherwise, the tractor may be installed. However, in this case either the implement depth or the tractor forward speed should be reduced to maintain the motion.

#### Plowing depth

The plowing depth had a negative affect on  $F_a$ , it increased as plowing depth increased (Figure 4) and that occurred due to the increase in the draft force which increased the tractor wheels slip, and hence reduced the tractor forward speed which resulted in lower  $F_a$ . However, the reduction in the forward speed increased the time required to plow a unit area (hectare) and this resulted in higher fuel consumption requirement and thus increased  $F_a$ .

The results revealed the operating depth of 15cm gave higher  $F_a$  than operating depth of 10cm but by a small amount (0.52 kg/ha), however, the operating depth 20 cm gave higher  $F_a$  with great differences than that of operating depth of 15 and 10cm, 12.35 kg/ha and 12.78 kg/ha respectively. This great difference between  $F_a$  of operating depths of 15 and of 20cm is related to the high reduction in forward speed of the tractor with operating depth 20cm due to the high draft force. The high draft force of operating depth of 20cm was related to the greater volume of soil

## Tractor fuel consumption per ...

manipulated by the plow, higher moisture content and greater soil strength with depth. Thus, to save fuel the implement should be operated at shallow depth when the deep operating depth is not necessarily for crop growth.

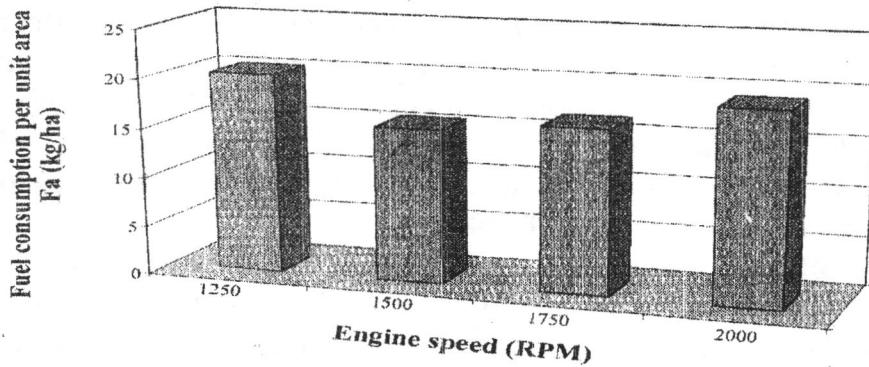


Figure 2: The relationship between the tractor fuel consumption per

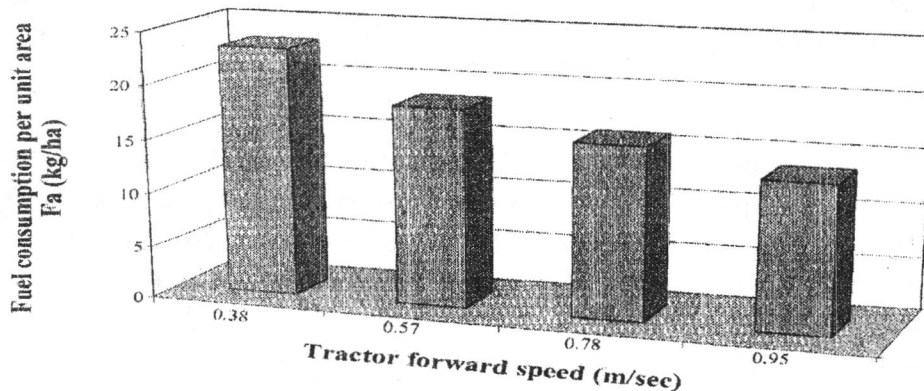


Figure 3: The relationship between the tractor fuel consumption per unit area and the tractor-implement combination

### The interaction effect of the tractor forward speed and the weight added to the tractor driving wheels on the fuel consumption per unit area

The positive effect of the tractor forward speed on  $F_a$  was further increased when 300kg was added to the tractor driving wheels (Figure 5).

In fact, the added weight reduced the tractor wheels slip through increasing the soil strength underneath the tractor tire, particularly at higher forward speed which leads to increase the forward speed of the tractor and thus a greater plowed area per unit time was achieved. To illustrate that a numerical example is taken, when the tractor forward speed was increased from 0.38 to 0.85m/sec,  $F_a$  decreased from 23.98 to

14.3 kg/ha (40%) without adding weight, but when 300kg was added to the tractor driving wheels,  $F_a$  decreased to 12.8 kg/ha (50%). Therefore, for lower  $F_a$ , the tractor should be operated at higher forward with addition weight to its driving wheels.

**The interaction effect of tractor engine and forward speeds and the weight added to the tractor driving wheels on the fuel consumption per unit area**

The lowest  $F_a$  (9.63 kg/ha) was recorded for engine speed of 1500 rpm, the highest forward speed (i.e., 0.85m/sec) and the added weight of 300 kg (Figure 6). This combination of parameters combined the advantages of each single parameter in reducing the fuel consumption of fuel resulted in lower  $F_a$ . While the second lowest  $F_a$  (12.24 kg/ha) was also achieved by the highest forward speed and the added weight of 300kg with engine speed of 1750 rpm. To save greater amount of fuel and hence lower plowing cost the first above parameters combination should be used. As an example, the total area advocated for planting in Iraq is about 176000 ha. When the Zetor tractor 6901 was used at engine speed of 1250 rpm, forward speed of 0.38m/sec. (slow speed) and without addition weight to its driving wheels, the total fuel requirement to plow this area may be 46567500 L (on average, the hectare required 26.61 kg of fuel to be plowed). This amount of fuel would cost about 465.675 millions of I.D (Iraqi Diner), ( i.e \$ 3.1045 millon) when one litter costs 10 I.D. However, when the same tractor is used at engine speed of 1500 rpm, forward speed of 0.85 m/sec. (highest forward speed tested for engine speed of 1500 rpm) and addition of 300kg to its driving wheels the required amount of fuel decreased from 46567500 L to 16852500 L. This amount of fuel (16852500 L) would cost about 168.5million I.D (i.e \$ 1.123million) and that would save about 297.5 million I.D. (i.e \$ 1.98 millon) which is lower by 61%. However, the saved cost depends on the tractor mechanical performance as it becomes older and its tire of traction become smoother and the soil moisture content is higher the saved amount of money is lesser. Therefore, to save fuel in preparing the soil for planting a suitable engine speed and the highest forward speed should be chosen as well as a proper weight should be added to the tractor driving wheels to obtain the best combination of parameters to save fuel and to reduce the soil preparing cost.

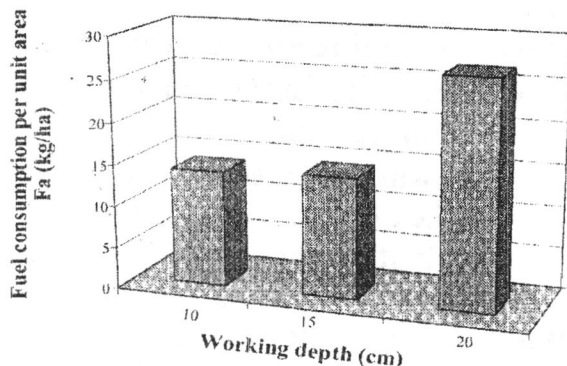


Figure 4; The relationship between the fuel consumption per unit area and the working depth.

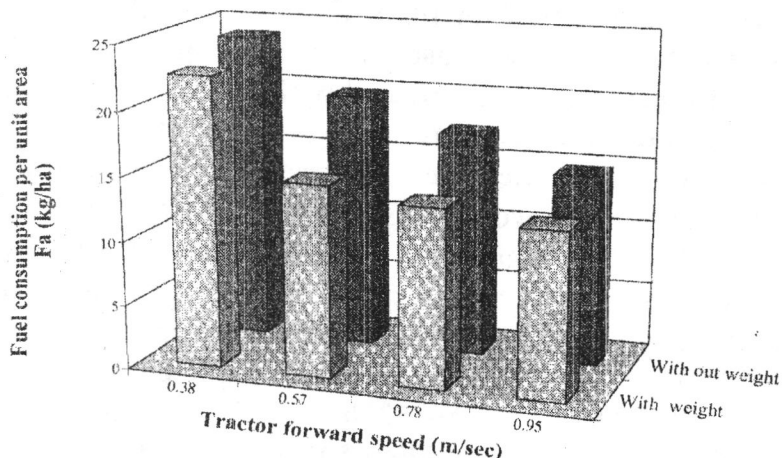


Figure 5; The effect of the tractor forward speed and the added weight on the fuel consumption per unit area.

### The interactiv effects of tractor forward speed, Plowing depth and weight added to the tractor driving wheels

The addition of weight to the tractor traction wheels reduced  $F_a$  for all operating depth and that was done through the reduction of the dissipated energy at the contact area between the tire and the soil in form of slip energy. The lowest  $F_a$  (9.42kg/ha) was recorded for highest forward speed, shallow depth (10cm) and addition of 300kg to the tractor driving wheels (Figure 7). The superiority of the shallow depth on the deeper operating depths in producing lower  $F_a$  can be related to the lower draft force requirement which let the tractor move forward faster than the deeper operating depth and that resulted in greater plowed area per unit

time for the same fuel consumption which produces lower  $F_a$ . The addition of weight to the tractor traction wheels reduced  $F_a$  for plowing depth of 20cm appreciably compared with  $F_a$  without adding of weight. This means the addition of suitable weight to the tractor traction wheels could save great deal of fuel when plowing soil, particularly at deeper plowing depths. The results clearly showed that to save a great amount of fuel and hence to reduce the total cost of soil preparation for planting, the tractor should be used at engine speed of 1500rpm (engine speed of 1500rpm had the lowest specific fuel consumption (4), the highest forward speed which can allow the tractor- implement combination operates with out hindrance, shallow plowing depth (10cm) and addition of about 300kg to the driving wheels.

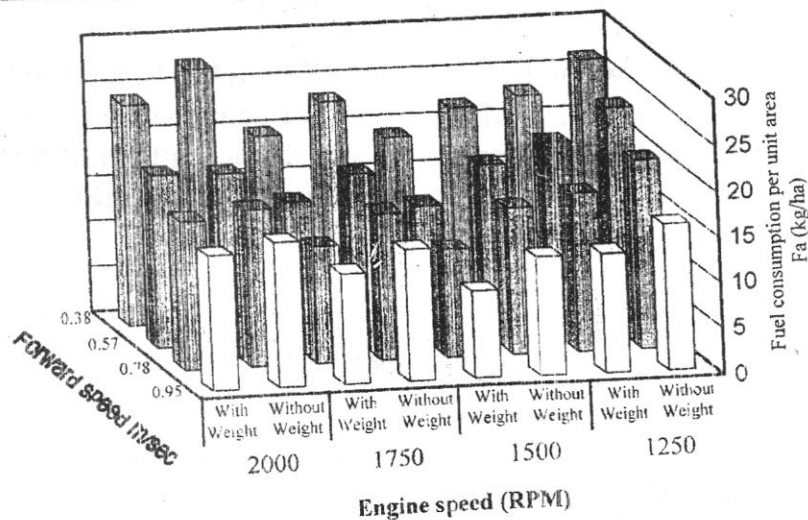


Figure 6: The effect of engine speed, tractor forward speed and the weight added to the tractor driving wheels on the fuel consumption per unit area,

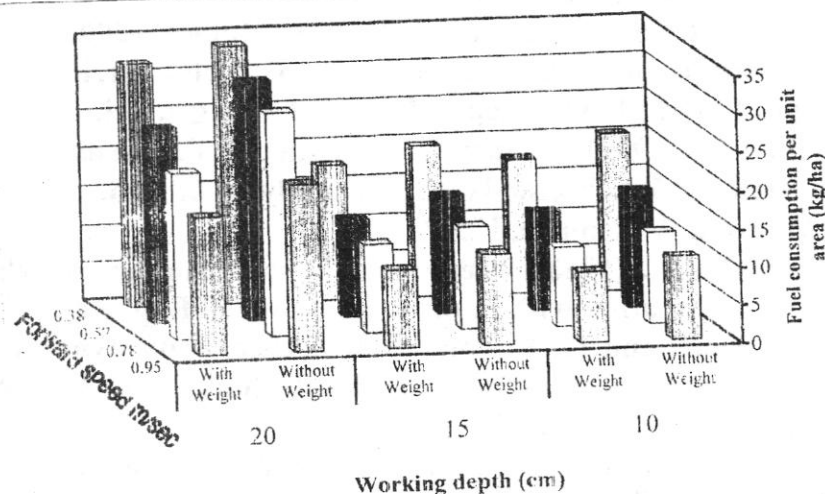


Figure 7: The effect of the tractor forward speed, the working depth and the weight added to the tractor driving wheels on the fuel consumption per unit area.

## CONCLUSIONS

- 1-Engine speed of 1500 rpm gave the lowest fuel consumption per hectare ( $F_a$ ) for all the forward speeds tested while engine speed of 1750Rpm became second.
- 2-The fuel consumption per hectare decreased as the tractor forward speed increased.
- 3-The addition of weight to the tractor driving wheels (300kg) decreased the fuel consumption per hectare considerably for all engine speeds, forward speeds and plowing depths tested.
- 4-The fuel consumption per hectare decreased as the plowing depth decreased.
- 5-The lowest fuel consumption was recorded for highest tractor forward speed, engine speed of 1500rpm, plowing depth of 10cm and added weight of 300kg.
- 6-The interaction between the parameters which are mentioned in point (6) could save about 61% of the total cost required to plow one hectare compared with slowest forward speed, deepest plowing depth, highest or lowest engine speed and without addition weight to the tractor driving wheels.

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## استهلاك الوقود لوحدة المساحة وعلاقته بسرعة المحرك

### والسرعة الامامية للجرار وعمق الحراثة

شاكر حنتوش عداي\* صالح اسماعيل نجم\*\* ماجد صالح حمود\*

### الملخص

يقيم استهلاك وقود الجرارات الزراعية التي تستخدم لاجراء العمليات الزراعية بكمية الوقود المستهلكة الحراثة مساحة معينة من التربة (كغم/دومم او كغم/هـ). وهذا يساعد بصورة كبيرة على تحديد كمية الوقود المطلوبة لحراثة او تحضير مساحة معينة من التربة وبالتالي تكاليف شراء الوقود. نفذت التجربة باستخدام جرار زيتور ٦٩٠١ مزود بمحرك رباعي الاشواط رباعي الاسطوانة. طول الشوط وقطر الاسطوانة ١١٠ و ١٠٢ ملم على التوالي. ونسبة الانضغاط للمحرك ١ : ١٧. استخدمت اربع سرع محرك ١٢٥٠، ١٥٠٠، ١٧٥٠ و ٢٠٠٠ دورة/دقيقة لتنفيذ التجربة واربع سرع امامية مع كل سرعة محرك  $G_{3h}$ ،  $G_{4h}$ ،  $G_{5h}$  و  $G_{1L}$  وثلاثة اعماق حراثة ١٠، ١٥ و ٢٠ سم لتحميل المحرك. اظهرت النتائج تفوق سرعة المحرك ١٥٠٠ دورة / دقيقة على سرع الاخرى حيث اعطت اقل كمية وقود لوحدة المساحة (كغم/هـ) كما اعطت اعلى سرعة امامية ولجميع سرع المحرك اقل كمية وقود مستهلكة لوحدة المساحة. واعطت سرعة المحرك العليا ٢٠٠٠ دورة/ دقيقة والعمق ١٠ سم اقل كمية وقود مستهلك لوحدة المساحة من السرعة ١٢٥٠ دورة/ دقيقة.

ادت اضافة ٣٠٠ كغم وزن الى عجلات دفع الجرار الى خفض كمية الوقود المستهلك لوحدة المساحة ولجميع سرع المحرك والسرعة الامامية للجرار واعماق الحراثة.

سجلت اقل كمية مستهلكة لوحدة المساحة لسرعة المحرك ١٥٠٠ دورة/دقيقة والسرعة الامامية العليا ٠,٨٥ م/ثا والعمق ١٠ سم واطافة وزن الى عجلات دفع الجرار بمقدار ٣٠٠ كغم وهذه العوامل المتداخلة قللت من كمية الوقود المستهلكة لوحدة المساحة بمقدار ٦١% وكذلك تكاليف الوقود عند مقارنتها بوسرعة المحرك ١٢٥٠ دورة/ دقيقة والسرعة الامامية البطيئة وبدون اضافة وزن.

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