Journal of Soil Sciences and Agricultural Engineering

Journal homepage: www.jssae.mans.edu.eg
Available online at: www.jssae.journals.ekb.eg

Utilization of The Tractor Hydraulic Device to Operate Reciprocating Mowers

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ABSTRACT

Due to the ease and excellence of the hydraulic transmission, this research is concerned to transmit power from tractor to a reciprocating mower using a hydraulic cycle. The theoretical consideration and the previous results from different studies were used to determine a suitable of a hydraulic motor, which give a sufficient torque needed to cutting different stems. Field experiments were performed on clover crop "M.C" of 25.92%, w.b., to evaluate the performance of the developed mower. At forward speeds of 0.89, 1.29, 1.42 and 1.72 m/s and knife speeds of 2.2, 2.6 and 2.9 m/s. Results showed that, after development operation, the consumed power and actual cutting height decreased by 17.32% and 10% respectively at forward speed of 1.72 m/s with cutting knife speed of 2.2 m/s. Furthermore, the actual field capacity increased by 9% under the same previous variables. To achieve the highest efficiency of cutting height, which is 90.2%, it is recommended to operate the cutting knife at a speed of 2.9 m/s with a forward speed of 0.89 m/s for developed mower.

Keywords: reciprocating mower, cutting force, hydraulic power, efficiency of cutting height

INTRODUCTION

The hydraulic power is useful to use at transmit the mechanical power particularly at low speeds also can used to rotate in both direction. This fact can applied in active powered of agricultural machinery at utilize the hydraulic motor which transfer the energy to mechanical operating devices. The specification of hydraulic motor, type and the operation required are the most important to select the best motor with the available pump which use by machine to function properly. Awad et al. (2012) indicted that, using the hydraulic transmission system instead of the mechanical transmission system decreased the power requirements and the fuel consumed about 18.4 %, when converting the mechanical transmission of rotary plow to the hydraulic transmission.

Cutting devices are classified based on the cutting mode for which they are designed. Impact cutting and shear cutting are the commonly used cutting modes in bioenergy harvesting machinery. Reciprocating sickle bar mowers cut the crop by slicing it between a moving knife sections. The cutter bar mowers are of two types: (1) single oscillating element with a fixed finger bar or (2) dual oscillating elements. Single cutter bars with different finger intervals double oscillating cutter bars: double knife bars without fingers or one cutter bar and one finger bar moving in opposition CIGR (2019). The cutting force for the flat blade was higher than the serrated blade for cutting miscanthus stems Liu et al. (2012). Reciprocating-knife mowers were usually made for smallholdings and orchards rather than for lawns, also known as Kraines (2013). The forward speed for the single oscillating element is about (5–7 km h^{-1}), whereas the dual oscillating elements have relatively higher forward speeds (8–9 km h^{-1}) Shastri et al. (2014).

The dual oscillating elements either have dual oscillating knives or an oscillating knife and an oscillating finger bar. The oscillating knife and oscillating finger bar type are more robust and better suited for cutting crops close to the forward, whereas the dual oscillating knives type is vulnerable to soil and rocks because the guards do not protect it. Unsupported and partially supported cutting requires that the cutting force is sup-ported by the plant's structural rigidity or inertia. Hence, cutting can only occur when the resistive forces of the plant exceed the consumed cutting force. Since cutting forces generally decrease with decreasing cutting speed in grass like stems, it is possible to define a critical cutting speed in which cutting forces exactly equal the reactive forces of the plant Persson (1987). The number of stems in (cm^2) of cereal crops (0.2–0.8) and (2–2.1) stem/cm^2 for grass crops and clover. The required work needed to cut (1cm^2) of cereal crops (1–2 N/cm^2) and (2–3 N/cm^2) for grass crops and clover, (Ahmed, 2012). A clean cut requires the stem to be severed above the critical speed. It also ensures significantly less stem deflection, which results into lower and uniform stubble height. Critical cutting speeds in grass are typically, about 25 m s^{-1}, but commercial impact cutting machinery operates at 60 m s^{-1} or higher cutting speeds Ismail et al. (1993).

Cutting processes in hay and forage machinery can be supported or unsupported. Unsupported cutting is often referred as inertial or impact cutting because the cutting force is supported by the inertia of the plant. The impact cutting occurs at high blade speeds (60–80 m s^{-1})

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DOI: 10.21608/jssae.2019.79697

Srivastava et al. (2006). Supported cutting occurs at lower speeds (3 m s^{-1}) in a scissor like action as the crop is sheared between the blade and ledger plate Tuck et al. (1991). For a specific crop, the cutting energy depends on stem diameter, cutting speed, blade type, blade geometry, and height of cut. For example, the energy consumed to cut sugar cane stems was proportional to the stem diameter Kroes and Harris (1996). Cutting throughout the stroke of the reciprocating mower results in uniform stubble height and reduce speak cutting forces. Stems can be supported in three different ways while cutting: upper shear, lower shear, and double shear. Impact cutting typically requires more energy but does not require sharp blades or ideal crop conditions Tuck et al. (1991). For example, shear cutting of grass stems (about 2.5 mm diameter) consumed 30 mJ per stem, whereas impact cutting energy consumed 100–1,000 mJ per stem O'Dogherty and Gale (1986). Higher energy in impact cutting is attributed to increased blade-stem friction and increased acceleration of the plant stem. High speed unsupported cutting may result in greater plant compression and deformation leading to elevated power usage Persson (1987). Thicker stems, such as those found in Miscanthus and corn, are often composed of strong node and weak Internodes sections may be hollow or non-hollow and more uniform than the nodes. Moisture content affects the strength of plant stems by changing the internal turgor pressure in plant cells. Cutting of plant stems occurs when the pressure exerted by the cutting blade exceeds a critical value, which ranges from 9 to 30 N mm^{-2} for various plant materials. Plant cutting results in multiple modes of tissue failure. Initial knife penetration causes localized plastic deformation, followed by significant buckling and deformation as the knife advances. As the knife continues to advance, the fibers in the stem are deflected and eventually fail in tension. The plant stem is also deformed and compressed ahead of and to the sides of the knife. These compression effects alone may account for 40–60 % of total cutting energy Srivastava et al. (2006).

Generally, the research aims to determine the best-studied parameter cleverness levels for synchronize operation between hydraulic motor and reciprocating mower. The developed system can evaluated by determining the cutting force, efficiency of cutting height and consumed power.

MATERIALS AND METHODS

This study is carried out to develop and evaluate the performance of convert the motion of reciprocating mower from mechanical to hydraulic system (Fig 1).

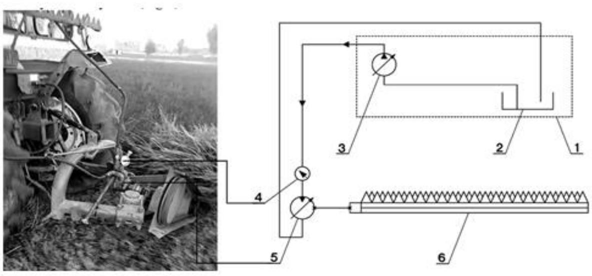

Fig. 1. A diagram of the proposed development of mower

1- Boundary of tractor 2- Oil tank 3- Hydraulic pump
4- Pressure indicator 5- Hydraulic motor 6- Reciprocating mower

Theoretical consideration

To determine the suitable specifications of a hydraulic motor for operate the reciprocating mower, it must determine the stem cutting force, consumed torque and consumed power. To achieve the above knowledge the following common formulas can be used:

$$F = W \times A$$

$$A = \frac{V_f}{V_k}(b \times S)$$

$$T = F \times L$$

$$P = (F \times V_k) \times 10^{-3}$$

Where;

F : expected cutting force for cutting plants along cutter bars width, (N),
W: required work needed to cut 1cm^2 of clover, 2–3 N/cm^2 (Ahmed, 2012),
A : cutting area, for one knife stroke along the cutting bars width, (m^2),
V_f: forward speed of mower, (m/s),
V_k: knife speed, (m/s),
b : operating mower width, (m),
S : knife stroke, (m),
T : mean torque on knives cutter bar, (N.m),
L : length of the connecting arm of the used reciprocating mower, (m),
P : expected power, (kW),

The technical specification of reciprocating-knife mower under the study is shown in Fig. (2) and table (1). Thus, at substituting in the previous equations by the following values of knife speed about (V_k=3m/s), mower forward speed of (V_f=1.72m/s), A=0.02526m^2 and L=0.12m, the expected values of cutting force, torque and power which needed to operating the mower were 993.5 N, 119.2 N.m and 2.98 kW respectively.

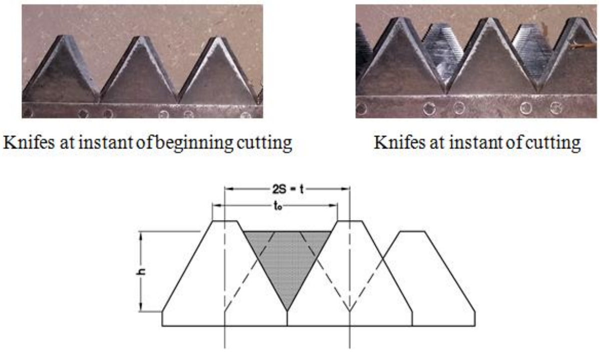

Fig.2. The technical specifications of blade's cutter bar

Then, the suitable power of hydraulic motor that is consumed to operate the reciprocating mower must be more than 2.98 kW. The technical data of suggested hydraulic motor and the reciprocating mower were tabulated in table (1).

Source of power

The Daedong tractor model D4351 with 32 kW (43 hp) and 540-1000 rpm was used as power source in all treatments. The discharge of the hydraulic tractor pump was 31.7 l/min with output pressure of 120 bars.

Clover properties

Some properties of clover crop at harvesting time are clover M.C of 25.92 %, w.b, (SD = 1.34 and CV = 5.36%); average of stems number 1785 in square meter (SD=36.54 and CV = 1.7%); average of stem height recorded 30.76cm (SD = 1.9 and CV = 5.7%) and average of stem diameter of 1.22mm (SD = 0.1 and CV = 9.1%).

Experimental procedure

The field experiments carried out to evaluate the developed drive system on efficiency of cutting height and consumed power in field. The studied variables of the field experiments were; forward speeds of 0.89, 1.29, 1.42 and 1.72 m/s represent (3.3, 4.6, 5.1 and 6.2 km/h) and cutting knife speed of 2.2, 2.6 and 2.9 m/s.

Table 1. Some technical specifications of hydraulic motor and used mower

Implement	Specifications
Hydraulic motor	Displacement (ml/rpm): 51.7 Max pressure. Drop (Mpa): cont 14; intermittent 17.5; peak 20 Max torque (N.m): cont 93; intermittent 118; peak 135 Speed range: 10 – 775 rpm Max flow: 40 l/min Max output power: 7 kW Mass 6.5 kg
Reciprocating mower	Cutter-bar, type; double moves in opposite directions Model; Busatis 1102 Cutting width (b) 152 cm Knife stroke (S) 38 mm Number of blades in the top cutter bar (20) Number of blades in the bottom cutter bar (Z) 21 Blade type; sickle sections (the upper blade with bottom-serrated and the lower blade with top-serrated) Distance between two moving blade, (t) Distance between two parallel edges, (t_o) Cutting deep length for two blades, (h) The length of the connected arm of knife (L) 12 cm

The number of experiments were 72 each one plot was 1.75 × 150 m width and length respectively. All experiments were repeated three times with sample size of 50 randomized from the field. Finally, experiments were designed in split split plot design. The collected data of different treatments were analyzed statistically by regression analysis and mathematically achieved using Excel program 2013.

Measurements:

Efficiency of cutting height

According to Hanna and Suliman (1986), the efficiency of cutting height (E_C) was calculated as follow:

$$E_C = \frac{H_a - H_b}{H_a} \times 100$$

Where;

H_a : height of plant stands above the soil before cutting, cm and
H_b : height of stubble after cutting (height of cut), cm.

Actual field capacity

Actual field capacity (AFC) was calculated according to Suliman *et al.* (2003) as follows:

$$AFC = \frac{1}{A_t / 60} \quad fed\, h^{-1}$$

Where;

A_t = Nt + Tt + Pt (h. fed^{-1})
***A_t*: total actual cutting time per fed, min. fed^{-1};**
Nt: time of maintenance and lubrication, min. fed^{-1};
***Tt:* turning time, min. fed^{-1} and**
***Pt*: parasitic time, min. fed^{-1}**

Consumed power

The consumed power, "P" kW for mower (mower powered by mechanical system, "MMS" and mower powered by hydraulic system, "MHS") can be estimated by grade difference between fuel consumption, in load and without load. Then, the net fuel consumption (F_c) l/h used to cut stems estimated. According to Hunt (1983) and Rangasamy *et al*. (1993) equation:

$$P = \frac{F_c}{3600} \rho_f x LCV x 427 x \eta_{th} x \eta_{mec} x \frac{1}{75} x \frac{1}{1.36} \quad (kW)$$

Where;

ρ_f : density of fuel, kg/l (for diesel = 0.85),
LCV : calorific value of fuel (10000 Kcal/kg),
427 : thermo-mechanical equivalent, J / Kcal,
η_{th} : thermal efficiency of engine (≈ 35%for diesel engines) and
η_{mec} : mechanical efficiency of engine (≈ 80%).

Actual cutting force

Actual cutting force (F) was calculated according to the following equations:

$$F = \frac{P_r}{V_k} \times 10^{-3} \quad (N)$$

RESULTS AND DISCUSSOINS

Actual cutting height and efficiency of cutting height

Fig. (3) shows the effect of forward speeds on actual cutting height and efficiency of cutting height at different knife speed for both of the conventional mower, (mower powered by mechanical system, "MMS") and developed mower, (mower powered by hydraulic system, "MHS"). The relationship between actual cutting height and forward speeds has a direct proportion but it has an inversely proportion with the knife speed and vice versa, for efficiency of cutting height. The highest efficiency of cutting height was 90.2% at forward speed of 0.89 m/s and knife speed of 2.9 m/s, while the actual cutting height was 3cm at the previous variables for MHS. But for MMS, the efficiency of cuting height and cutting height were 87% and 4 cm respectively under the same pervious conditions. Also, the mean average of cutting height was 6cm at knife speed of 2.9 m/s with efficiency of cutting height of 80.45%, at neglected the effect of forward speed for MHS. However, for MMS, the mean average of cutting height and efficiency of cutting height were 7.25 cm and 77.2% respectively at the same previous conditions. Genraly, the actual cutting height was increased by increasing the forward speeds and decreased by incrasing the knife speed. These results may due to the increase in forward speed raise the mounted machine from the soil surface this cause the high in cutting hight. Also, at low speed level the stems faced the mower knives at the adjust mower height while at high knife speed the crowded stems between knives may cause less cutting height. Also, it is cleare that the cutting height dereased by about 10 % at forward speed of 1.72m/s with knife speed of 2.9m/s, after making the development.

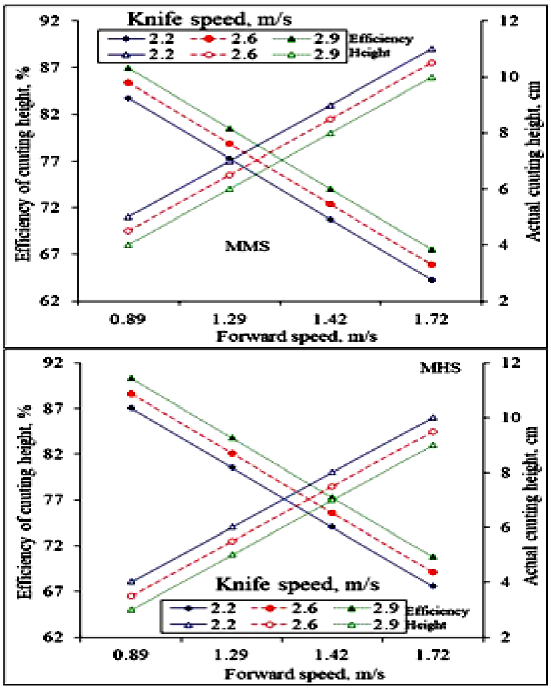

Fig. 3. Effect of forward speeds on actual cutting height and efficiency of cutting height at different knife speed for MMS and MHS.

This result may be attributed to drive mower with hydraulic motor achieved more balance and stability during the mower is working. For MMS, the maximum and minimum efficiency of cutting height were 87 and 64.2 % found at forward speeds of 0.89 and 1.72 m/s and knife speed of 2.9 and 2.2 m/s. On the other hand, for MHS, the maximum and minimum efficiency of cutting height were 90.2 and 67.5 % found at forward speeds of 0.89 and 1.72 m/s and knife speed of 2.9 and 2.2 m/s. Also, it is clear that efficiency of cutting height increased by about 3.7% for developed mower. These results may due to many resons as machine swimming more stems faced the mower which was cause jam-packed between knives and incline the stems. Finally, data analyzed showed that there was a significant effect of the knife speed and forward speed on cuttig height and efficiency of cutting height with all treatments ($p<0.05$).

Actual field capacity

The relationship between actual field capacity and mower forward speed with different knife speeds of cutter bar was illustrated in Fig. (4) for both of "MMS" and "MHS". Forward speeds and knife speed have a direct proportion effect on actual field capacitr, by increasing both of forward speed and knife speed the acual field capacity icreased. The results indicated that the highest value of actual field capacity was 0.88 fed/h for MMS and 0.98 fed/h for MHS, which obtained at adjusted forward speed at 1.72 m/s and knife speed with 2.9 m/s. Also, it is clear that, after development operation, the actual field capacity increase by 11.4 %.

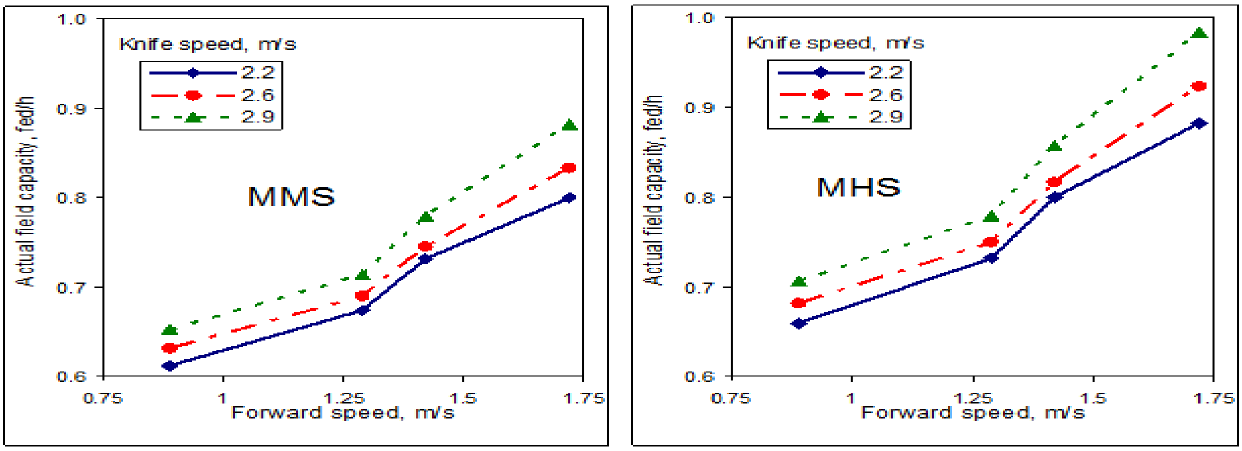

Fig. 4. Effect of forward speeds on actual field capacity at different knife speed for MMS and MHS.

This is due to using the hydraulic system to operate the mower reduces mechanical contact points, which leads to reduced maintenance and lubrication time also give more flexibility in field maneuvering and reducing turs time and then an increase in the actual field capacity of the mower. While the lowest value of actual field capacity was 0.61 and 0.66 fed/h for both cases MMS and MHS concquantly, at knife speed of 2.2 m/s and forward speed of 0.89 m/s. The multiple regression analysis shows the effect of forward speed "V_f", and knife speed "V_k" on actual field capacity "AFC" for MHS by the follow equation, which illustrates the relation as see in Eq. (1):

$$AFC=0.14\ V_k+0.32\ V_f \qquad R^2=99\% \qquad (1)$$

The regression analysis declares that both of forward speed and knife speed have a direct proportional with actual field capacity. The factors affected the "AFC" arranged as the following ascending on relative to analysis of variance as follow. Forward speed (the p-value from analysis as $P_{v1}=2.62\times10^{-7}$) > knife speed (the p-value from analysis as $P_{v2}=1.54\times10^{-6}$).

Actual cutting force

To focus the effect of experimental factors on the actual cutting force, for both of MMS and MHS (Fig. 5) indicated this effect. It was easy to obvious that increasing the forward speed, the actual cutting force increased. It was increased by one and a half times by increasing forward speed from 0.89 to 1.72 m/s at knife speed of 2.9 m/s MMS. For MHS, it was increased by 1.3 times at the same previous conditions.

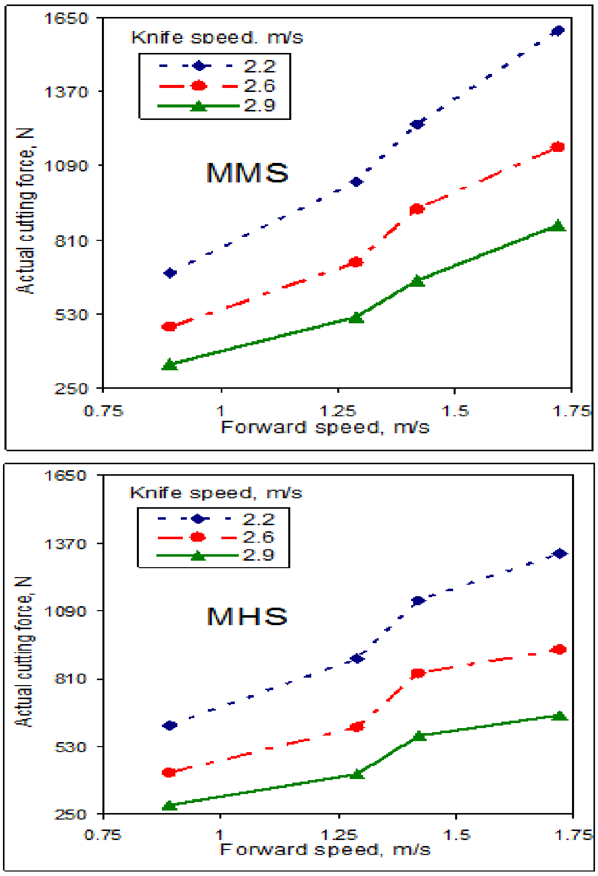

Fig. 5. Effect of forward speeds on actual cutting force at different knife speed for MMS and MHS.

Nevertheless, the actual cutting force values decreased by 48.8% and 50.3 % for MMS and MHS consequently at increasing the knife speed from 2.2 to 2.9 m/s at operational forward speed of 1.72 m/s. This result may be attributed to increase in the dynamic cutting area by increasing the forward speed, also low in the cutting knife speed increasing the cutting resistance attributed to increase in actual cutting force. Finally, the highest values of the actual cutting force were 1601.3 N for MMS and 1326.8 N for MHS at operational forward speed of 1.72 m/s and knife speed of 2.2 m/s for both cases. In addition, it is clear that the actual cutting force decreased by 24% at forward speed of 1.72 m/s and knife speed of 2.9 m/s after making the development. This result may be attributed to drive mower with hydraulic motor achieved more balance and stability during the mower is working.

Consumed power

Fig. (6) describe the relationship between the forward speed, and the consumed power, for both of MMS and MHS at different cutting knife speed. In general, by increasing the forward speed the consumed power increased. In the other hand, by increasing the knife speed the consumed power decreased. For MMS, the highest value of consumed power was 3.5 kW achieved at operational knife speed, of 2.2 m/s at forward speed of 1.72 m/s. However, the lowest value was 0.989 kW at operational knife speed, of 2.9 m/s and forward speed of 0.89 m/s.

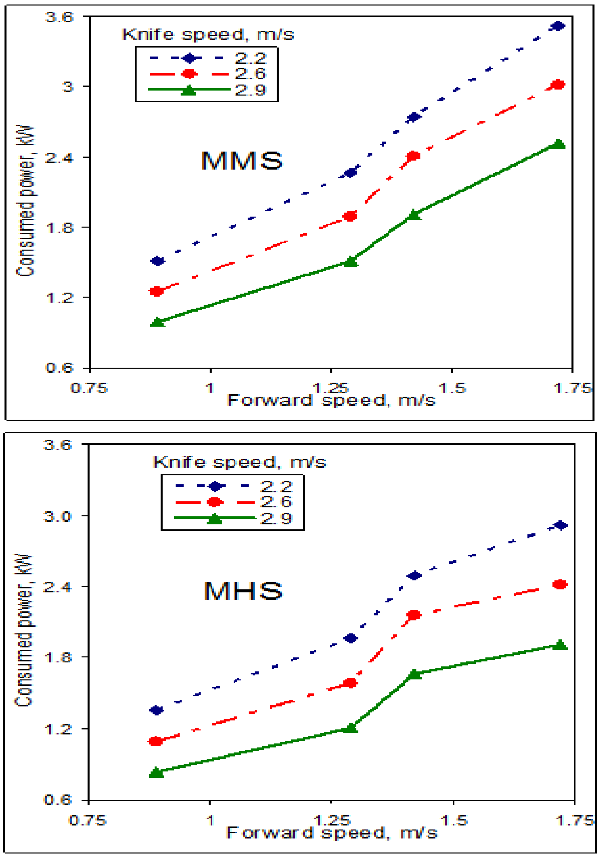

Fig. 6. Effect of forward speeds on consumed power at different knife speed for MMS and MHS.

For MHS, increasing the forward speed from 0.89 to 1.72 m/s, the highest value of consumed power was 2.91 kW. This achieved at operational knife speed of 2.2 m/s. The lowest value was 0.83 kW at operation knife speed, of 2.9m/s. This result may be attributed to increase in the dynamic cutting area by increasing the forward speed, also low in the cutting knife speed increasing the cutting resistance attributed to increase in consumed power. For MHS, after development, the consumed power decreased by 17.14% at operational condition of 1.72 m/s for forward speed and 2.2 m/s for knife speed. This may be attributed to drive mower with hydraulic motor achieved balance and stability during the mower is working.

Furthermore, the regression analysis showed that the consumed power was directly proportional to forward speed but it inversely proportional to knife speed. The mathematical model can describe the consumed power "P" and the forward speed "V_f" speeds could be as follows:

Knife speed, m/s	MMS	MHS
2.2	$P = 1.9135\ V_f$ $R^2 = 0.9379$	$P = 1.6549\ V_f$ $R^2 = 0.9495$
2.6	$P = 1.6368\ V_f$ $R^2 = 0.9165$	$P = 1.3782\ V_f$ $R^2 = 0.9068$
2.9	$P = 1.3283\ V_f$ $R^2 = 0.8935$	$P = 1.0697\ V_f$ $R^2 = 0.8993$

The multiple regression analysis showed that the forward speed "V_f" and knife speed "V_k" had a highly significant linear relationship with consumed power "P" for both of MMS and MHS. The high effect of studied factor is "V_k" for both two cases. The best-fit equation to explain the correlation between the "P" and the both of "V_f" and "V_k" could be indicated as follows:

$$\mathbf{P = b_1 V_f - b_2 V_k} \qquad (2)$$

The regression coefficient (b_1 and b_2) and coefficient of determination (R^2) are plotted in table (2) for the both two cases.

Table 2. Values of constants, coefficients determinations of Eq. (2) for two cases.

Different cases	Regression coefficients		(R^2)
	b_1	b_2	
MMS	2.460	-0.454	0.9885
MHS	2.012	-0350	0.9786

Finally, data analyzed showed that there was a significant effect of the knife speed and mower forward speed on consumed power with all treatments ($p<0.05$).

CONCLUSION

Drive mower with hydraulic motor achieved balance and stability during the mower is working. The obtained results concluded that, the efficiency of cutting height increased by 9.7%, but the actual cutting force dereased by 24%, for developed mower than the conventioml mower. In the other hand, by increasing the knife speed the consumed power decreased. To achieve the highest efficiency of cutting height, which is 90.2%, it is recommended to operate the cutting knife at a speed of 2.9 m/s with a forward speed of 0.89 m/s for developed mower.

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استخدام الجهاز الهيدروليكي للجرار لتشغيل المحشات الترديه

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نظراً لسهولة وتميز نقل الحركة هيدروليكيا يهدف هذا البحث إلى رفع كفاءة إستخدام المحشة الترددية لتعمل بمحرك هيدروليكي بديلا عن عمود الإدارة الخلفي للجرار. ولتحديد قدرة المحرك الهيدروليكي اللازمة لتشغيل المحشة الترددية. تم إجراء دراسة نظرية ومقارنتها بنتائج الأبحاث والدراسات السابقة للوصول إلى توافق بين المحرك الهيدروليكي المختار والمضخة الهيدروليكية للجرار للحصول على العزم الكافي للقطع. تم تنفيذ التجارب الحقلية لحش البرسيم الجاف (الزريع أو التربية) لتقييم أداء المحشة بعد التطوير عند سرعات تقدم للجرار (0.89، 1.29، 1.42، 1.72 م/ث) ولسكينة القطع (2.2، 2.6، 2.9 م/ث). وقد أشارت النتائج المتحصل عليها بعد عمل التطوير المقترح إلى انخفاض كلا من (القدرة المستهلكة - ارتفاع الحش) بنسبة 17.32% و 10.00% على التوالي عند سرعة تقدم 1.72 م/ث وسرعة مقدارها 2.2 م/ث لسكينة القطع. كما زادت السعة الحقلية للمحشة عند نفس المتغيرات السابقة بنسبة 9%. لتحقيق أعلى كفاءة قطع 90.2% يوصى بتشغيل سكينة القطع عند سرعة 2.9 م/ث وسرعة تقدم 0.89 م/ث للمحشة الترددية المدارة بمحرك هيدروليكى.