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PERFORMANCE OF HELICAL MOWER IN CUTTING MAIZE STALKS

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ABSTRACT

This research aims to utilize, study and evaluate some engineering parameters, which affect the mechanical performance of the helical mower during the cutting operation of maize stems. These parameters were; knife edge angle (α), diameter and length of helical knife (d), cutting speed (N) and distance between fingers (L_0). These parameters and their effects on the mechanical performance of the helical mower were assessed using four criterions during the cutting operation. The obtained data of the experimental work revealed that the previous parameters strongly affect the mechanical efficiency of cutting operation. They also showed that the conventional edge angle, cutting rotary speed, distance between fingers and diameter and length of helix which achieve the best cutting of maize stems rang between; 21-24°, 1000-1200 rpm, 80-120 mm and 180-200 mm respectively.

INTRODUCTION

Removing the stem portion from row crops to obtain the optimum harvest such as cotton and maize after manual harvesting is the target of all who are working in this field. There is a number of factors that influence row crops harvesting. An important one of them is cutting the stem portion (Ismail, et al., 1993).

The conventional cutter for the majority of agricultural field crops is the reciprocating mower. Cyclic unbalanced inertia forces induced by the sickle and its reciprocating motion characterize this. The unbalance forces produce cyclic loads on the drive members and the frame and thus limit the maximum operating speed of the cutter and forward speed of the field machine.

Also, frictional forces, which oppose the sliding action of the cutting knife, are produced. Both types of forces waste input energy and cause rapid wear.

Miller (1968) employed a rotary stalk cutter consisting of a rotor assembly with elliptical shaped disks arranged at angle to the center shaft. The stationary cutting edges were curved ledger blades, concentric with the peripheral surface of the rotor disks for approximately 90°. Miller mechanism produced better

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results in a moderate stand of alfalfa when the rotor moved forward and up rather forward and down. Bledose and Porterfield (1971) concluded that sharp blades were superior and optimum mechanical performance occurred with a 46° of rotor knife angle, 0° of ledger orientation, 63.5 mm of cutter height and 3118 rpm rotor speed when the feed rate was 111.3 mm per revolution.

The elliptical cutter knife has an inherent dynamic unbalanced moment perpendicular to the axis of rotation created by centrifugal forces; however, the knife is statically balanced. This configuration was chosen for fabrication simplicity (Durfee, et al., 1977). The outer fibers of many stems appeared to have failed by tensile load applied to the stem (Durfee, 1975). Incomplete shearing could have resulted from failure of the stem to enter the cutting zone of the elliptical knife before the knife began its shearing action when the rotational speed was slow compared with forward velocity.

Durfee et al. (1977) concluded that at rotary speeds from 700 to 1300 rpm and forward velocities from 0.96 m/s to 1.79 m/s; optimum mechanical performance was based on the joint criteria of high quality cutting. Field data indicated that the optimum performance occurred when the ratio of knife tip velocity to forward velocity was 11.7 to 13.8.

Persson (1987) indicated that increasing the edge angle above 45° results in increasing the induced stresses in the tool edge region which means decreasing the working life of the tool. While Habib et al. (2001) mentioned that an optimum value for the cutting edge angle is found to be around 38°, which minimizes the induced stresses in the cutting tool and hence increasing its life.

To improve the mechanization of removing the stems from field after manual harvesting of corn ears, more attention should be given to the harvesting operations with the latest technology available in the market. This would in fact solve partially some of the problems facing Egyptian farmers.

Therefore, the main objective of this study is to modify a conventional mower to be used as mower with helical cutting surface in removing the maize stems as one of the main row crops. The modified mower with helical cutting was also tested and examined to determine the mechanical performance of modification.

THEORETICAL APPROACH

The investigated mower was modified to harvest the crops of hard stalks such as maize. Fig. (1) shows the meeting points between the plant stalks and the cutting edge of the helical surface knife. During the cutting operation the helical surface knife is transported from point "A" to point "B", the plant stalk may move until stop between the helical surface knife and the finger Fig. (2-A). During this operation the helical cutting surface make an angle of "φ" with the horizontal. To fined the theoretical approach for this operation, the following relationship is investigated:

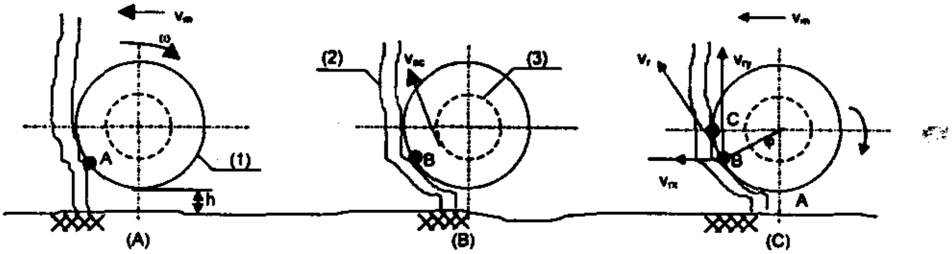


Fig. (1): The cutting edge of the helical surface knife via plant stalk

A) The meeting cutting surface with stalks.
B) Bend the plant stalks affected by linear speed of mower after Δt of feeding speed.
C) The beginning level to cut the stalks.
1- Surface of helical cutting 2- Plant stalks. 3- Mower shaft

1- Mower speeds via holding stalk angle

For primary observation, different speeds are affecting the cutting plant stalks and harvesting performance such as:

1- The liner speed of investigated mower (v_m), m/s.

2- The peripheral speed of helical cutting surface (v_r), m/s.

3- The peripheral speed of mower shaft (v_{ac}), m/s.

Referring to Fig. (2) and resolving the peripheral speed of helical cutting surface (v_r), in tow components "v_{rx}" and "v_{ry}" relative to the two coordinates "x" and "y", the total speed of helical surface at point "B", as shown in Fig. (2) may be following form;

$$\overrightarrow{v_t} = \overrightarrow{v_m} + \overrightarrow{v_{rx}} \quad (1)$$

Substituting the values of "v_{rx}" in Eq.1 then,

$$\overrightarrow{v_t} = \overrightarrow{v_m} + \overrightarrow{v_r} \cos\varphi$$

$$\therefore \quad v_t = v_m + \omega r \cos\varphi \quad (2)$$

Where:

v_t = The total speed of helical cutting surface at point "B", m/s.

N = The number of helical shaft revolution, rpm.

φ = The bending angle, (the angle formed between two positions of point "B" within certain time denoted as the bending angle, degree.

r = Helical radius, mm.

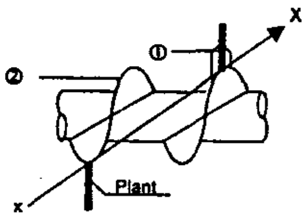


Fig. 2-A: Cutting stroke
1- Finger 2- Helical mower

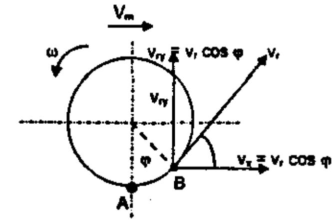


Fig. 2: Velocity at point "B" on the helical cutting surface.

On the other hand, the relationship between the different speeds acting upon the plant stalks is illustrated in Fig. (3). The resultant between the linear speed of mower "v_m" and the component speed of helical cutting surface in direction of coordinate "x" may be represented as "v_t" in the polygon BoB_1o_1.

Similarly, the resultant speeds between "v_t" and "v_{ac}" may be represented in "BB_1D_1D" polygon and take the values of "v_α". The "v_α" speeds will push the stalks in its direction until cutting. The angle between the level of "v_α" and the level stalks cutting is denoted by holding angle "λ".

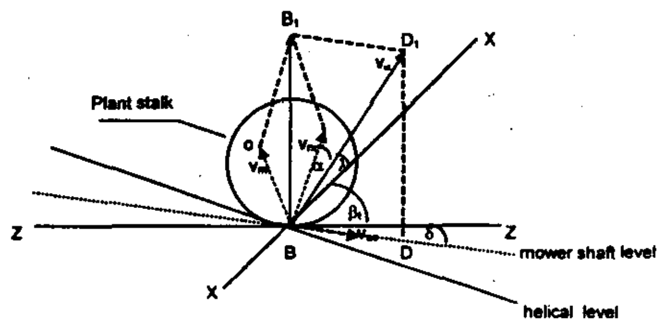


Fig. 3: Polygon of velocities.

The holding angle "λ" can be calculated from Fig. (3) as follows:

$$\lambda = 90^\circ - (\beta_t + \alpha_1 + \delta) \quad (3)$$

Where:

β_t = The angle between the perpendicular level on helical surface and the "zz" level, degree.

α_1 = The angle between the "v_{rx}" and "v_α" speeds, degree.

δ = The angle between the mower shaft surface and "zz" level.

V_{ac} = Mower shaft speed.

V_m = Linear speed of mower.

V_{ry} = Speed of stalk at point "B" in "y" direction.

V_{rx} = speed of stalk at point "B" in "x" direction.

V_r = The component of speeds of V_m and V_{rx}.

V_α = The component of speeds of V_r and V_{ac}.

From Eq.3, the values "λ" may be depended on the (α_1) which affect by the "v_{rx}" and "v_α" speeds, while the (δ) and (β_t) angles may be considered as constant values at same helical pitch and diameter. On other hand, the Eq.3 may be divided into two variables: the design and operation variables. The angles (δ) and (β_t) are considered as design angles while the angle (α_1) is considered as operation variable.

2- The friction stalk angle via holding angle

Generally, from experimental observation, during one revolution of investigated mower, indicated that, there are three stages may be carried out until cutting the plants there are bending, holding and cutting stages.

The distribution forces (Fig. 4) upon the stalk may be as follows:

F_f = The friction force = μF_n

μ = Coefficient of friction, $\tan\phi$

ϕ = The friction angle, degree.

F_n = The effective force on stalk.

F_t = The total force.

F_h = The hold force = $\tan\lambda\ F_n$.

Referring to Fig. (4), the "F_t" may be the summation of "F_n" and "F_h" forces and to hold the plant the holding force for the stalks must be bigger than the friction force ($F_h > F_f$).

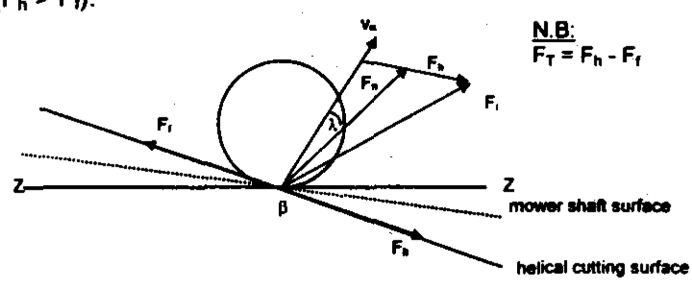


Fig. 4: The force polygon.

Thus, the balancing equation may be equaled:

$$F_t = F_h - F_f \tag{4}$$

Then the above equation at moment of equilibrium will be equal:

$$O = F_h - F_f$$

$$F_h \geq F_f$$

According to the physical properties of crops.

$$F_n \tan\lambda \gtrless \mu F_n$$

$$F_n \tan\lambda \gtrless F_n \tan\phi$$

$$\lambda \gtrless \phi \qquad (5)$$

Equation (5) represents the situation of helical cutting processes. There are three probability; the first is the holding angle "λ" less than the friction angle (ϕ) ($\lambda < \phi$). This stage is known as the bending stage. The second is the holding angle equal the friction angle ($\lambda = \phi$) and this is called the holding stage. The third stage is ($\lambda > \phi$) and this is known as the cutting stage.

3- Factors affecting bending angle

The angle formed between two positions of stalks moves from point "B" within "A" position at certain time is considered as the bending stage (Fig. 5).

N.B.

$\tan(\beta - \delta) = \frac{OO_1}{OA}$

$\cos\varphi = \frac{BO'}{O'A}$

$\tan\beta_t = \frac{AB}{BO} \times \frac{OA}{BO'}$

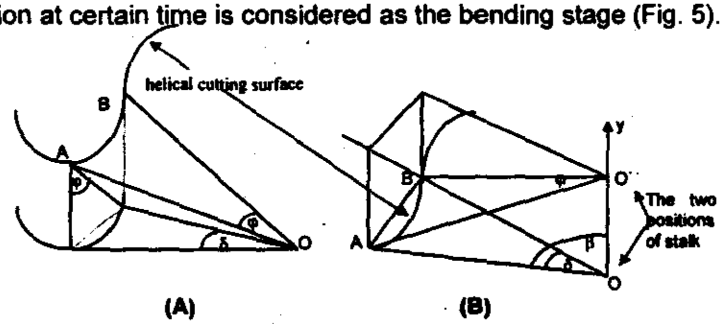


Fig. 5: The bending stage during cutting operation.

From geometry shape of Fig. (5-B), and from ΔO_1AB, then

$$\cos\varphi = \frac{O_1B}{O_1A} = \frac{OO_1}{O_1A} \qquad (6)$$

But $\Delta\, OO_1B$ we found that

$O_1B = OO_1$ then

$$\therefore \cos\varphi = \frac{OO_1}{O_1A}$$

by multiple the equation in OA/OA then,

$$\cos\varphi = \frac{OO_1}{OA} \times \frac{OA}{O_1A} \qquad (7)$$

The values of OO_1/OA is equal led to $\tan(\beta-\delta)$ while the value of OA/O_1A is equal to $\cos\beta_t$.

By substituting in Eq. 7, then

$$\cos\varphi = \tan(\beta - \delta)\frac{1}{\tan\beta_t}$$

$$\cos\varphi = [\frac{\tan(\beta - \delta)}{\tan\beta_t}]$$

where β = The angle between the knife line action and Oy axies.

Then;

$$\varphi = arc^{-1} \cos[\frac{\tan(\beta - \delta)}{\tan\beta_t}] \quad (8)$$

By substituting the value of tan "β" in Eq. 8, then

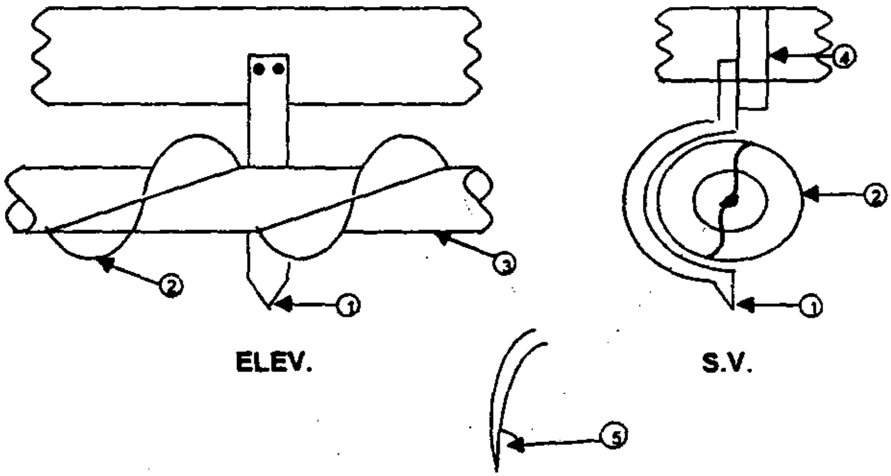
$$\varphi = arc^{-1} \cos[\frac{\tan(\beta - \delta)}{\tan(90^\circ - \lambda - \alpha_1 - \delta)}] \quad (9)$$

Eq. 9 represents the forces affecting stalks performance during one revolution of investigated mower. The values of bending angle may influenced by "β, δ, α_1, λ" angles.

MATERIALS AND METHODS

The helical mower has been designed by other's to harvest the crops of hard stalks such as maize. The investigated machine was drawing and photographically as shown in Fig. (6). The helical mower machine was manufactured in workshop at Ag. En. Mansoura University. The cutting and transmission units are the two main components of the investigated machine. The cutting unit is composed of the cutting plate which located in the highest side of helical guide. The other edge of this plate is sharpened to conform the cutting angle. The helical angle is welded on the mowering shaft. The mowering shaft has a length of 1000 mm. The distance between the top of two successive helices is considered as the helical stroke. The mowering shaft was fixed in each end by two bearings to reduce the rotating resistance. The fingers were distributed along a fixed bar, where the highest side of helical cutting edge come in nearest level with each of the fingers. According to the mower forward speed and the helical shaft speed, the stalks of plants will be pushed unit the clearance between he fingers and the cutting edge of helical plate dectreases at which the stalks are broken.

A 1m mower is used to test maize crop at Samannoud farms (Governorate of El-Gharbia). The cutting parameters such as knife edge angle, knife-cutting bar speed, the change in dimensions for the each of pitch length of helical mower fixed diameter and distance between the ends of adjacent fingers were tested as dependent variables. Due to previous studies, mowing forward speed of 3.6 km/h (1 m/s), the average of clearance between helical surface and finger of 10 ± 2 mm, fingers angle 75 - 80° and cutting-bar height 10 cm., were chosen when the effect of other parameters were tested. So, an area of 1.22 fed (each having 320 m long × 16 m wide) was divided into plots and sub-plots. Each subplot, which represents the experimental test unit was 1 m wide and 20 m long. Tests were carried out and controlled by efficiency of good cut (represents plants completely cut) or non cut of the maize plants.



A- Sketched view

1- Finger 2-Helical edge 3- Mower shaft 4- Frame 5- Knife helical angle

B- Photographically view

Fig. 6: The general view of investigation mower.

Four cutting-bar speeds of 600, 800, 1000 and 1200 rpm were considered. Four levels of edge angles of 18, 21, 24 and 27 degree were examined. Four levels of pitch length to diameter of helical of 160, 180, 200 and 220 mm were tested at four levels of distance between the ends of adjacent fingers 80, 100, 120 and 140 mm. A spedometer was employed to measure all cutting speeds.

The "S.C.10" variety of maize (Zea maize) was used during this experimental work. Seeds were planted on the 1st of May 1995, in salty clay soil (40,60 % silt, 47.10 % clay and 11.81 % sand) with seeds planting rate of 12 kg/fed. The average plant characteristics are summarized and listed in Table (1). All plant heights and lengths were measured using common methods and plants diameter was measured by venire.

Table 1: Average maize plants and cutting characteristics.

Measured	Dim.
Average plants	
Intensity of plants / m^2	10±2
Height, mm.	2150
Moisture content, %	50 ± 25
Cut. area dia., mm at height of cutting, mm	20-30
Knife clearance, mm.	1 ± 0.2
Cutting bar height, mm.	100

RESULTS AND DISCUSSION

To obtain the optimum operation conditions of developed mower, three parameters were investigated, the number of helical shaft revolution, the edge angle, the helical cutting, and the space between the fingers.

1-The number of helical shaft revolutions (N):

From the theoretical approach, the (Eq. 2) provide the relationship between the helical shaft revolution "N" and the total speed of helical cutting (vt) affecting the cutting efficiency. This result may be increasing the total values of helical cutting speed tend to decrease the holding angle "λ" because of consequently improving the cutting efficiency.

Figs. (7 to 10) show the best fitted curves for the relationship between the number of helical shaft revolution and the cutting efficiency (CE%) at different helical cutting diameters.

For the duration of the experimental work, the percentage of cutting stalk (CE%) increased with the shaft speed (N) until reaching the maximum cutting efficiency. After that, the rate of cutting reaches to constant level with decreasing in level of cutting percentage. The maximum values of cutting percentage (99.5 %) were found at 1000 rpm and 180 mm of helical cutting diameter.

The cutting efficiency bend to increase from 85 % to 90 % as the cutting surface speed is increased from 600 to 1200 rpm at 160 of helical diameter and 21° of edge angle (Fig. 8).

The increase in speed (vt) leads to increase in friction between mower surface and plant stalks (φ), therefore improving the holding angle (λ) then improving the cutting percentage. The result agreed with Eq. 5 in theoretical part.

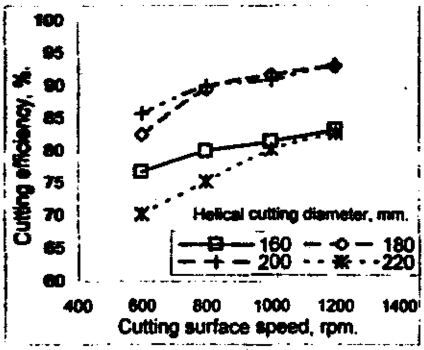


Fig. 7: Cutting efficiency via cutting surface speed (rpm) at edge angle (18°).

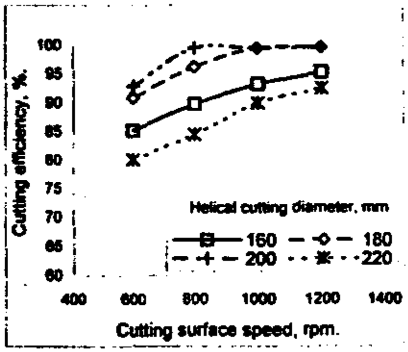


Fig. 8: Cutting efficiency via cutting surface speed (rpm) at edge angle (21°).

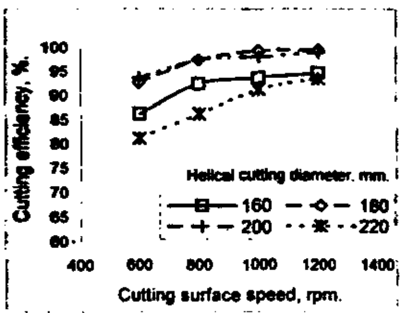


Fig. 9: Cutting efficiency via cutting surface speed (rpm) at edge angle (24°).

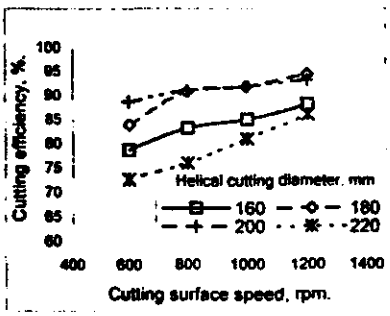


Fig. 10: Cutting efficiency via cutting surface speed (rpm) at edge angle (27°).

2- Edge angle (α):

Fig. 9 and Fig. 10 clearly indicated that, the greatest cutting efficiency (99.5%) was achieved at cutting speed of 1000 rpm, 180mm cutting diameter and edge angle of 24°. While it decreased to 91.75 % when the edge angle was increased to 27°. This means that increasing the edge angle from 24° to 27° decreases the percentage of cutting efficiency by 7.79 %.

As the edge angle of cutting surface (α) is increased from 18° to 21° and from 21° to 24° the cutting efficiency is increased. While it decreased with increasing the edge angle from 24 to 27°.

3- Helical cutting parameter:

From the theoretical approach, the relation between helical cutting diameter and pitch of helical length was assumed to be constant and this relation is referred to as helical cutting parameter.

Figs. 7 to 10 revealed the effect of helical cutting diameter on the percentage of cutting efficiency. It was more complicated because, the relation between helical cutting diameter and the number of cutting surface speed affected the cutting speed. The percentage of cutting efficiency was found to be increase with increasing the helical cutting diameter from 160 mm to 180 mm. Meanwhile increasing the diameter led to narrow different from 200 to 220 mm lead to decrease the percentage of cutting efficiency. However the rate of decreasing was greater from 200 to 220 mm than that from 180 to 200 mm of helical diameter.

4- Span between fingers:

At the span between fingers of 80 mm, the maximum cutting efficiency was found at 21° edge angle and 1000 rpm helical shaft revolution (Fig. 11). While it was found at 22° of edge angle and 100 mm of span between fingers (Fig. 12). However at 120 mm span between fingers, the greatest value was found at 23° of edge angle.

From the above discussion reveals that as the helical diameter of mower is increased, the cutting efficiency increase making the mechanical performance more efficient. The change in helical cutting diameter must be coinciding with the edge angle to obtain the highest values of cutting efficiency (Figs. 11 to 14).

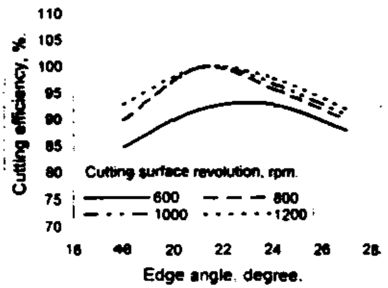


Fig. 11: Cutting efficiency via edge angle at (80 mm) span between fingers

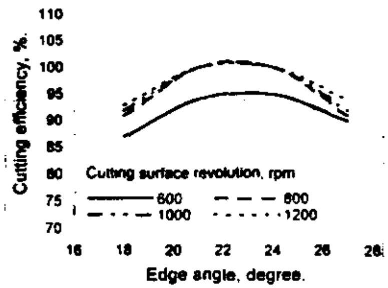


Fig. 12: Cutting efficiency via edge angle at (100 mm) span between fingers

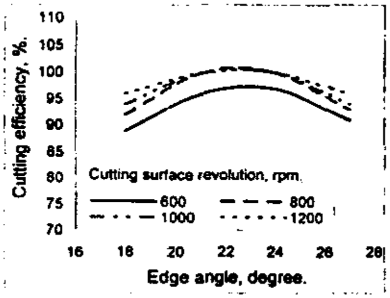


Fig. 13: Cutting efficiency via edge angle at (120 mm) span between fingers.

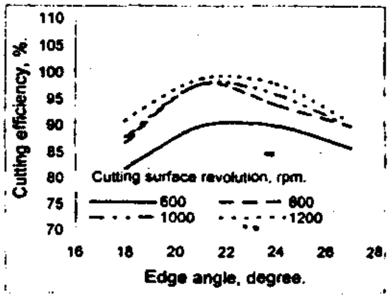


Fig. 14: Cutting efficiency via edge angle at (140 mm) span between fingers.

CONCLUSION

Based on the obtained results, the specific conclusions can be listed as follows:

1- The percentage of cutting efficiency (CE %) increases with the increase of the numbers of helical shaft revolution (N) until it reaches the maximum cutting efficiency. After that, the rate of cutting becomes constant. The maximum values of cutting percentage were found at helical shaft speed of 1000 rpm and 180 mm of helical cutting diameter.

2- The cutting efficiency increases with the increase of the edge from 21° to 24°, while it decreases with increase of the edge angle from 24° to 27° at the same helical shaft speed.

3- The percentage of cutting efficiency usually increases with the increase of the helical cutting diameter from 160 to 180 mm. But when the cutting diameter increases from 200 to 220 mm the percentage of cutting efficiency decreases.

4- The maximum cutting efficiency was found at 80 mm span between fingers, edge angle 21° and 1000 rpm helical shaft speed.

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الملخص العربي

خصائص محشة بريمية لقطع سيقان الذرة

د/ مجدى عبد الهادى السعدنى*

تهدف تلك الدراسة إلى الوصول إلى أنسب الأبعاد وظروف التشغيل الحقلية للمحشة البريمية (المقترحة) التى تم تصنيعها فى ورش قسم الهندسة الزراعية بكلية الزراعة جامعة المنصورة. والمصممة لحش سيقان النباتات ذات الأقطار الكبيرة نسبيا (مثل الأذرة وعباد الشمس). وقد شملت الدراسة المتغيرات التالية: زاوية شطف الحد القاطع α بحدود ٢١° : ٢٧°، وقطر السكينة البريمية d المساوى لطول خطوتها L بحدود ١٦٠ : ٢٢٠ مم، وسرعة دورانية لعمود البريمة N بحدود ٦٠٠ : ١٢٠٠ لفة/دقيقة، ومسافة بين الحوافظ t_0 بحدود ٨٠ : ١٤٠ مم. وذلك للحصول على أعلى كفاءة حش. وقد توصلت الدراسة إلى:

١- بصفة عامة تزداد كفاءة الحش مع زيادة السرعة الدورانية لعمود البريمة، فأعلى كفاءة حش وجدت عند سرعة ١٠٠٠ لفة/دقيقة وقطر للسكينة البريمية ١٨٠ مم. وكذلك أوضحت النتائج أن كفاءة الحش تزداد من ٨٥ % إلى ٩٠ % مقابل زيادة السرعة من ٦٠٠ إلى ١٢٠٠ لفة/دقيقة عند قطر ١٦٠ مم وزاوية شطف الحد القاطع ٢١°.

٢- نقص كفاءة الحش من ٩٩,٥ % إلي ٩١,٧٥ % بزيادة زاوية شطف الحد القاطع من ٢٤° إلى ٢٧° عند نفس ظروف التشغيل السابقة بينما تزداد كفاءة الحش مقابل زيادة زاوية شطف الحد القاطع من ١٨° إلى ٢١° وكذلك من ٢١° إلى ٢٤°.

٣- زيادة كفاءة الحش بزيادة قطر السكينة البريمية من ١٦٠ إلى ١٨٠ مم، بينما إنخفضت كفاءة الحش إنخفاضا غير ملحوظ بزيادة القطر من ١٨٠ إلى ٢٠٠ مم بينما كان الإنخفاض ملحوظا بزيادة القطر من ٢٠٠ إلى ٢٢٠ مم.

٤- كانت أعلى كفاءة حش عند المسافة بين الحوافظ ٨٠ مم وزاوية شطف الحد القاطع ٢١° وسرعة دورانية لعمود البريمة ١٠٠٠ لفة/دقيقة. كما وجدت كفاءة حش عالية أيضا عند مسافة بين الحوافظ ١٠٠ مم وزاوية شطف الحد القاطع ٢٢° وكذا عند مسافة بين حوافظ ١٢٠ مم وزاوية شطف الحد القاطع ٢٣°.

لذلك للحصول على أعلى كفاءة حش ينصح أن تكون الأبعاد المستخدمة: قطر السكينة البريمية ١٨٠ مم، وسرعة دورانية لعمود البريمة ١٠٠٠ لفة/دقيقة، وزاوية شطف الحد القاطع من ٢١ : ٢١° ومسافة بين الحوافظ من ٨٠ : ١٢٠ مم.

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* مدرس الهندسة الزراعية – كلية الزراعة – جامعة المنصورة.