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# THE THEORETICAL AND FIELD SCOPES OF A DEVELOPED UNIT FOR HARVESTING SUGAR-BEET

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## ABSTRACT

Mechanical harvesting of sugar beet is not widely spread in Egypt, manual harvesting is a tedious and exhaustive job especially in the newly reclaimed land. The objective of this paper is to build and develop a simple liable and sugar beet harvester unit for small farms. The study is divided into two parts. The first is the theoretical study to determine the forces affecting on the lifting share during harvesting operation, and to find the mathematical relations of the forces affecting the beet lifting and damage. The second is the experimental field which, conducting under three forward speeds, three digging angles and three blade widths.

The theoretical study showed that both the horizontal "HF" and the vertical "VF" forces were gradually increased with both of tilt angle and share width. It also revealed that the effect of tilt angle was greater than the effect of share width on the horizontal force while their effect on the vertical force was almost the same. The field experiment was coincident with the theoretical study. Which,' at tilt angle, "23cm" share width and "3.5km/h" forward speed the share gave "98.5 %" of the beet lifting efficiency. Also the lowest percentage of beet damage was obtained at the above conditions but when the share width was "21cm" the share width of "23cm" is not recommended to be used with the developed share because of its irreguler effect.

## INTRODUCTION

Over 4070 of the world sugar production is produced from auger beet. In Egypt, the importance of this crop as a source of sugar Is increasing to meet the increasing consumption of sugar by Egyptian population. Therefore it is noticed that the cultivated area by such crop in Egypt is increased from 6000 fedd. in 1981, to 128000 fedd. in 1999 (Agric. Rec. Center 2000).

Because beet grows under different soils and climates, the roots and the tops develop differently in different areas, making it difficult to adapt machines to the various types of growth, soil and weed conditions. In Egypt, mechanical harvesting of beet is still not used to an appreciable extent. On the other hand, manual harvesting is so tedious and exhaustive job particularly in the newly reclaimed land where the scarcity of labors exist. Manual harvesting of beet required 5.2 manh/ton (Ade et al., 1979). Comparing mechanical harvesting with manual method, the results showed that mechanical harvesting reduced the needs of man power by 72.7% as reported by Maughan (1982). Allam (1984) found that the harvesting of one ton of beets required about 16-20 man power hour. This means that 320-400 man power hour were needed to produce about 20 ton of -beet per feddan.

Beet harvesters may be either tractor-mounted, trailed behind the tractor and/or self-propelled. Harvesting operation performed in several steps (Kepner et al., 1978) as follows; removing vegetative top portion at the desired height, appropriate disposition of the tops to prevent interference with the other steps, loosening and lifting the beets from the soil, and elevating the beets and separating them from the clods and other foreign material.

Bartha (1977) compared three types of beet harvesters. The results showed that the harvesting losses were depended mainly upon the field operations quality during sowing and harvesting. Ibrahim, et. al (1989) reported that the cost of lifting sugar beet roots using the developed blade was more economic, and it should reduce costs from 90 L.E. to 6 L.E. /feddan. The required force to extract sugar beet vertically was much less in wet soil than in hard dry soil. In dry soil the relative strength of the beet and the soil becomes big problem because of the possible damage of the beet during lifting (Hemeda et. al, 1992). To prevent this damage the lifting force must be as small as possible by the proper adjusting of the operating parameters. The disadvantage of lifting mechanisms are; the higher damage of roots, in taking soil, stones and trash (Mady, 1995). The rotation of the lifting wheels makes them more dependent on accurate steering than the static shares.

Therefore the aim of this investigation is to develop and evaluate a blade for digging and lifting sugar beet roots, and in the same time estimating its performance. Therefore, the stud consisted of two parts as follows:

**1- Theoretical study:**

a- Conducting theoretical analysis to determine the forces acting on the lifting share during harvesting operation.

b- To find the mathematical relations of the forces affecting the beet lifting and damage.

**2- Field testing:**

The experimental field were conducting under three forward speeds, three digging angles and three blade widths.

## THEORETICAL PREDICTIONS

Hemeda, et. al (1992) indicated that the machine share-lifter unit is subjected to three independent forces. These forces are the machine weight acting at the center of gravity, soil forces acting on the machine and the forces acting between the machine and the prime mover. The mathematical analysis was developed to provide an understanding to associate the parameters, involved in the lifting operation of sugar beet, according to the design of the lifting share. The forces acting on the share during harvesting process were also studied and geometrically analyzed. The force analysis was mainly performed to find the theoretical relationship of the forces affecting the lifting share concerning only the soil-tool interaction. Therefore, the effect of the implement weight was not taken into account. The mechanics of the designed lifting share based on the idea that most of beet portion is lifted with the surrounded soil segment, because of the action of tilt angle "$\alpha$" as shown in figure (1). The lifting share causes failure in the soil and separate it from the beet. A small portion of beet located beneath the share cutting depth is the only portion of beet subjected to the force of soil resistance of root lifting "$F_1$". As a result, this force is small, in the present study, comparing to other vertical forces and will be neglected.

**Forces acting on lifting share:**

The lifting share is subjected three forces (Fig. 1) as follows:-

1) The weight of soil and beet "W" acting at the center of gravity in vertical direction. The normal force "N" acting on the inclined surface due to the soil and beet mass is:

$$N = W \cos \alpha \qquad (1)$$

2) Soil forces:

   a) The soil-metal friction force ($\mu N$) acts in the direction of inclined surface and ($\mu$) is the soil-metal coefficient of friction.

   b) Soil-metal adhesion force (CA) acts in the direction of inclined surface [C: the oil-metal adhesion ($N/cm^2$) and A : the area of share surface ($cm^2$)].

   c) Cutting force "Z" acting on the horizontal direction.

$$Z = U\, h\, b \qquad (2)$$

Where:

U : the unit draft, $N/cm^2$
h: the cutting depth, cm,
b : the cutting width ($b = 2\,L \sin \beta/2$), cm,
L : the share length, cm, and
$\beta$ : the apex angle, degree.

3) Forces acting between the lifting share and the tractor.
   These forces are "HF" acting in the horizontal direction and "VF" acting in the vertical direction.

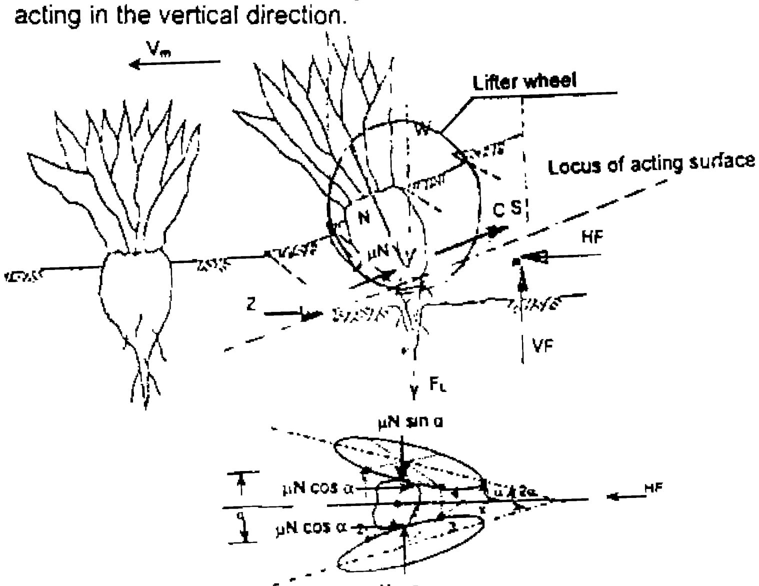



**Fig. 1: Forces affecting lifting share.**

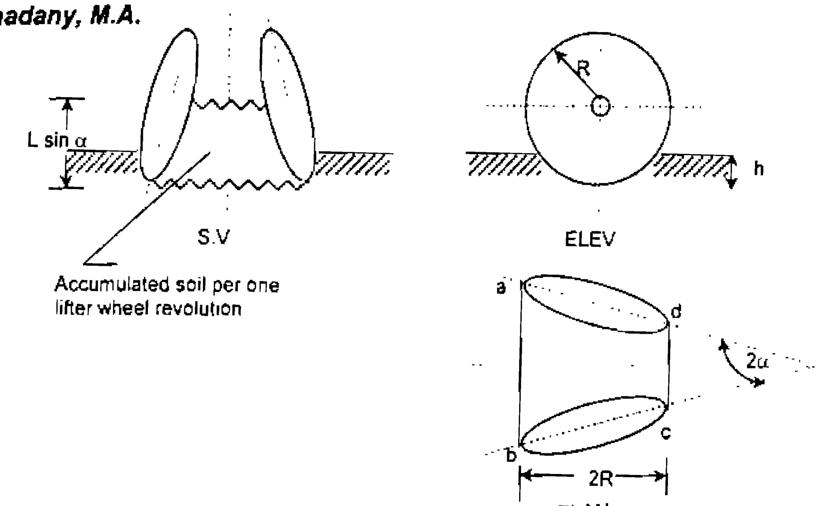



**Fig. 2: Geometrical relations of lengths for a segment of soil reacting to an inclined tool.**

Referring to Fig. (1) the analysis of forces in the horizontal direction will be:

$$\mathbf{HF = Z + N\,(\sin\alpha + \mu\cos\alpha) + C\,A\cos\alpha} \qquad (3)$$

Substituting the values of "N" and "Z" from equations (1) and (2) in Eq. (3):

$$\mathbf{HF = Uh\,b + W\cos\alpha\,(\sin\alpha + \mu\cos\alpha) + C\,A\cos\alpha} \qquad (4)$$

The mass of soil and beet could be obtained by :

$$\mathbf{W = W_b + W_s}$$

where:

$W_b$: beet mass in average is equal"40 N", N
$W_s$: soil segment mass, N.

The soil segment mass "$W_s$" may be calculated from the volume of the soil supported by the inclined tool. Fig. (2) shows a trapezoidal area that may be assumed to be supported by the tool. The area of the trapezoid multiplied by the depth of the area (width of tool) and the density of the soil gives the weight. By using the relationships indicated by Gill and Berg (1968), the mass of soil segment will be:

$$W_s = \frac{\rho b h_1}{10^3}\left(L + \frac{L_1 + L_2}{2}\right) \qquad (5)$$

Were:

$\rho$: wet bulk density of soil, $kN/m^3$
b : width of tool, cm,
$h_1 = h \sin(\alpha+\theta) / \sin\theta$, cm
$\theta$ : angle of forward failure surface ($\theta = 1/2\,(90° - \varphi)$)
$\varphi$ : soil internal friction angle ( 30° for clay soil),
$L_1 = h \cos(\alpha+\theta) / \sin\theta$, and

$L_2 = h_1 \tan\alpha$.

The same derivation applied to obtain "HF" was u sed to find the magnitude of the vertical force "VF":

$$VF = w\,(1 - \mu \sin\alpha \cos\alpha) - C\,A \sin\alpha \qquad (6)$$

The main objective of any soil-tool interaction is to minimize the resistance forces with the best machine performance. Incase of sugar-beet harvester, there are two resistance forces : the vertical force "VF" and the horizontal force "HF". Minimizing the vertical force leads to reduce the resistances during beet lifting operation. This means more beet lifting with minimum machine effort, i.e. increasing the lifting efficiency. On the other hand, minimizing the horizontal force is required to reduce the magnitude of draft force and thus reducing the amount cf beet damage, which occurred because of the pulverizing of soil segment. So, these forces have direct impact on damaging the beets during lifting operation and also affect the lifting efficiency.

In order to simplify the experimental work, the values of both constants and variables in equations (4) and (6) were substituted according to the following considerations:

**1. Soil parameters :**

The values of soil parameters for a clay soil, according to Text book of Ag. Mach. (2000) and Gill and Berg (1968) were:

$\mu = 0.577$, $\rho = 13.5\ kN/m^3$, $\theta = 30°$

**2- Tool parameters:**

The value of tool parameters, according to the design of lifting share, were:

$L = 60$ cm, $A = 1200\ m^2$, b= 19, 21 and 23 cm.

**3- The mode of operation:**

The values of the operation parameters, according to the experimental work, were:

$h = 15$ cm, $\alpha = 15, 20$ and $25°$ (degree) .

Substituting the values of the above parameters in Eq. (5) and consequently in equations (4) and (6) :

$$W_s = 6.075 \times 10^{-3} \sin(\alpha + 30)\,[4b + \cos(\alpha + 30) + \sin(\alpha + 30)\tan\alpha] \qquad (7)$$

$$HF = 105b + (40 + W_s)\cos\alpha\,[\sin\alpha + 0.577\cos\alpha] + 24\cos\alpha \qquad (8)$$

$$VF = [40 + W_s]\,[1 - 0.577 \sin\alpha \cos\alpha] - 24 \sin\alpha \qquad (9)$$

Figs. (3) and (4) show the graphical presentation of equations (8) and (9). Fig. (3) shows that the horizontal force "HF" gradually increases and the share width "b". The horizontal force was increased, by about 250 N, due to the increase of share width from 19 to 21 cm and from 21 to 23 cm for all tested tilt angles. While it increases, by about 100 N, with the increase of tilt angle from 15 to 25 for all tested share widths. Therefore, the effect of share width was greater than the effect of tilt angle within the experimental range. Because of the share width acts directly through the cutting force "Z" and indirectly through the soil weight "$W_s$" as indicated by equations (7) and (8).. Fig. (4) shows that the vertical force has the same trend of the horizontal force as explained before. Except that the effect of share width has almost the same effect of tilt angle within the experimental range. The vertical force increases, by about 40 N, due to the increase of share width. While it increases, by about 35 N, due to the increase of tilt angle from 15 to 25. The effect of share width was obtained only, as indicated in equations (7) and (9), from the soil mass.

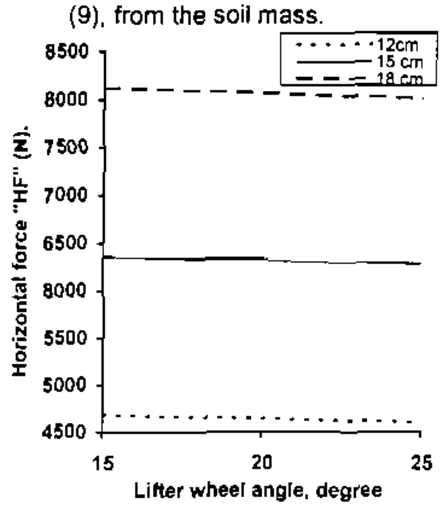



Fig. 3: Horizontal force "HF" Vs. tilt angle "α" at different share width "b".

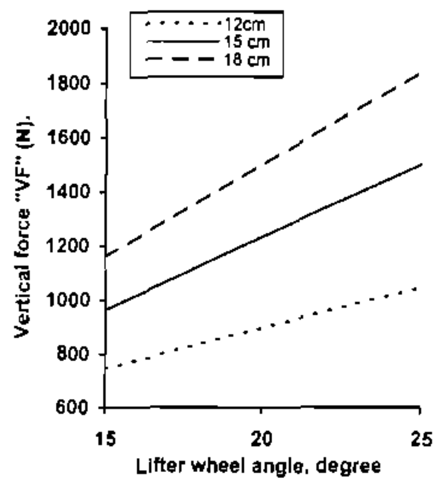



Fig. 4: Vertical force "VF" Vs. Tilt angle "α" at different share width "b".

## MATERIALS AND METHODS

The developed beet digger (Figures 5 and 6) is considered a share sweep with a fork shape including two wings with a flat cutter. The two wings of the blade could be controlled. The main parameters of such blade covering its shape and operating characteristic are:

1- Tilt angle (α) was adjusted from the three hitch points of tractor (lengthening for less depth, and shortening for more depth). Such angle facilitates the lifting of roots with some of loosing soil with-out damaging it.
2- Width of cutting (b) was calculated as a function of apex angle β (Fig. 5).
3- Length of blade (L) was fixed at 600 mm during the experiments (Fig. 5).

The blade was fixed on a frame which is made of (L) iron cross section (75 x 50 mm) with 1500 mm length and 450 mm width. The frame is furnished, with "2" blades and mounted on the tractor by "3" hitch points. It is also supplied with two depth wheels (Fig. 6).

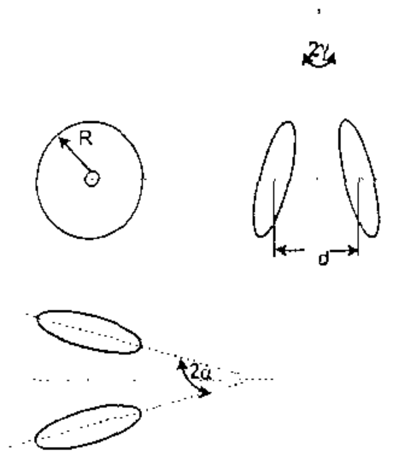



**Fig. 5: The main parameters of used digger.**
β = apex angle (degree; α = tilt angle, degree;
b = blade width, cm; L= share length, cm.

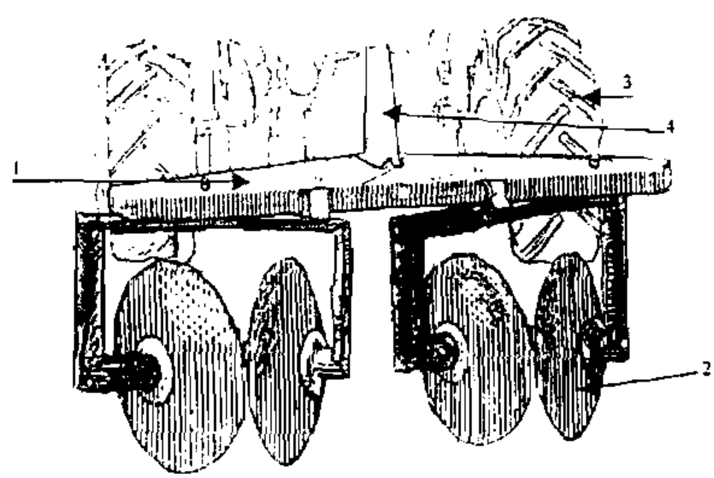



**Fig. 6: General view of developed digger.**
1- Iron frame; 2- the digger;
3- *penetration* wheel; 4- three hitching points.

The suggested implement is mounted on four wheels tractor to harvest two ridges of beet. The implement parts were constructed, and tested at farm of the Mechanization Department in Mansoura University, Egypt.

The sugar beet variety is Treble germ seeds (Beta Vulgaries L.), was used. The mean ridge spacing (Fig. 7) was 690 ± 30 mm while the planting spacing was 300 ± 50 mm, and ridge height was 225 ± 25.9 mm.

Experiments covered an area of 31.5 m width x 50 m long, 45 ridges and it was replicated 3 times. The experiment was carried out in clay soil with soil moisture content of 23.0; 25.20 and 27.60 at depths of 0-5; 5-10; and 10-15 cm respectively.

Three forward speeds (v) of 2, 3.5 and 5 km/h; three share digging angles (tilt angle, α) of 15, 20 and 25° and three share width "b" of 19, 21 and 23 cm were used during this study. The operating depth "h" is kepded constant during all experiment.

The effect of the above factors on the lifting efficiency of the sugar-beet "LE" and beet damage loss "DL" were studied. All tests were . repeated three times and the average was calculated. The dependent variables were the lifting efficiency of the beets "LE" and beet damage loss "DL". The two dependent variables were calculated according the following equations:

$$LE = \frac{W_L}{W_T} \times 100$$

Where:

$W_L$ : The mass of lifted beets, N

$W_T$ : The total mass of beets (lifted + un-lifted), N.

$$DL = \frac{W_d}{W_T} \times 100$$

Where:

$W_d$ : The mass of damaged beets, N.

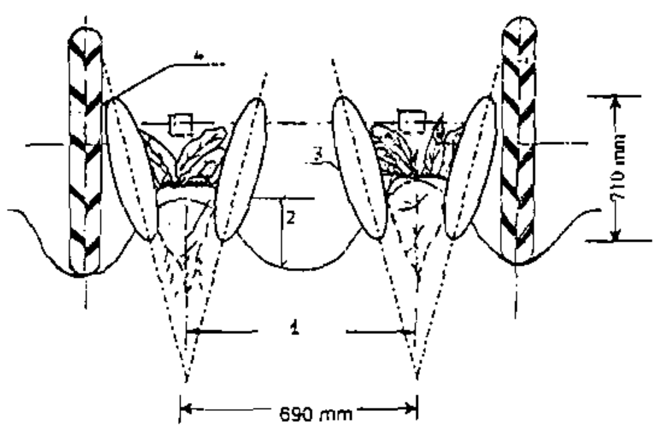



**Fig. 7: Dimensions of bet ridge and direction of digger action.**
**1- ridge spacing, cm; 2- ridge height, cm; 3- sugar beet digger; 4- tractor wheel.**

Computations were performed with the Statistical Analysis System (SAS, 2000). The analysis of variance (ANOVA) was. used to test the effect of the experimented independent variables on beet lifting efficiency and the beet damage.

## RESULTS AND DISCUSSION

**Lifting efficiency "LE %":**

Fig. (8) illustrated the effect of tilt angle via the values of lifting efficiency (LE, %) at different shear width and different forward speeds. It is easily noticed that "LE %" increases with increasing "$\alpha$" and share forward speed. The effect of "$\alpha$" on "LE %" was highest effect up to value of "$\alpha = 20$" degree then its effect decreased after wards until it become un-significant. The highest lifting efficiency of 98.5 % was gained at tilt angle of 20, share width 23 cm and forward speed of 3.5 km/h. Referring to the analysis of variance (table 1), the effect of share width on "LE %" not clear and not significant effect. But the effect of share width of 23 cm was irregular with forward speed.

The analysis of variance in table (1) shows a highly significant effect of the tilt angle on the beet lifting efficiency. There was also a significant effect of the forward speed an LE %. Because of the share width affect the vertical force "VF" as indicated in the theoretical study, by the soil weight. Therefore, this effect was small due to the smallest soil weight "$W_s$" was diminished during the operation.

**Table 1: Analysis of variance procedure (Anova) Dependent variable (LE);**

| Source | DF | Sum of square | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Model | 6 | 120.704 | 20.117 | 7.94 | |
| Error | 20 | 50.655 | 2.532 | | 0.002 |
| Corrected T. | 26 | 171.360 | | | |
| R. Square | c.v | | Rpt MSE | LE Mean | |
| 0.7044 | 1.6912 | | 1.5914 | 94.10 | |
| Source | DF | Anova SS | Mean Sq. | F value | Pr>F |
| Seed | 2 | 29.0488 | 15.5244 | 5.73 | 0.0108s |
| Shear width | 2 | 7.2800 | 3.6400 | 1.44 | 0.2611 |
| Tilt angle | 2 | 84.3755 | 42.1877 | 16.66 | 0.0001 |

**Dependent variable (DL);**

| Source | DF | Sum of square | Mean Square | F value | Pr>F |
|---|---|---|---|---|---|
| Model | 6 | 53.1281 | 8.854 | 37.38 | 0.0001 |
| Error | 20 | 4.7379 | 0.236 | | |
| Corrected T. | 26 | 7.8660 | | | |
| R.Square | c.v | | Rpt MSE | LE Mean | |
| 0.918 | 11.15 | | 0.486 | 4.365 | |
| Source | DF | Anova SS | Mean Sq. | F value | Pr>F |
| Seed | 2 | 3.90 | 1.95 | 8.23 | 0.0025 |
| Shear width | 2 | 2.21 | 2.11 | 8.89 | 0.0017 |
| Tilt angle | 2 | 45.01 | 22.51 | 95.01 | 0.0001 |

**Damage loss "DL %":**

Roots damage "DL %" is increased with decreasing the lifting angle "α" from 20 to 15° and reaches to its minimum value at "α = 20°" degree, then it increases after wards with the increasing "α".

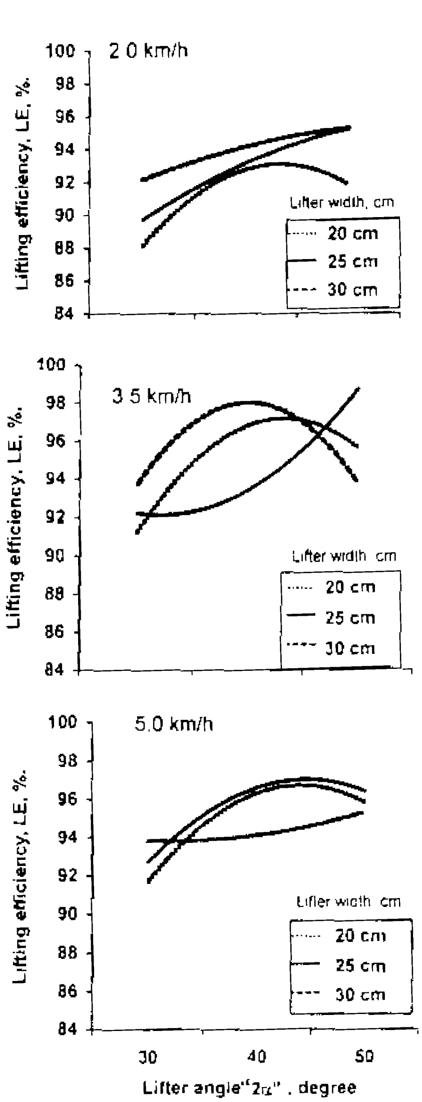
The previous results could be explained by increasing "α" the share pushing deeper in the soil which pushes the roots with adapted forces happing more damage.

On the other hand, the minimum value of "DL %" will be achieved at share with of 20 cm or more. Furthermore, there is no need to increase share width (b) more than 20 cm because there is no corresponding increase in "LE %" or decreases in root damage "DL", more over as it is known that any increases in "b" will lead to more power consumption. This will be explained by the value of max-root diameter which was less than 20 cm at contact surface with share.

Referring to table (1), it is clear that the roots damage "DL %" is highly effected by increasing forward speed [Pr > F = 0.0017]. For the share width of 19 cm, the maximum "LE" was about 97 % at 3.5 km/h forward speed and the minimum "DL" was about 3.2 % at the same speed. On the other hand the share width of 21 cm, the maximum "LE %" was about 97 % at 5.0 km/h and the "DL" was about 3.2 % at the same forward speed. While the minimum "DL" was about 2.5 % at 3.5 km/h.

Therefore, the share width of 19 cm was recommended to be used at forward speed of 3.5 km/h and α = 20°. This recommendation was agreed with the results obtained from the theoretical consideration.

Fig8,9



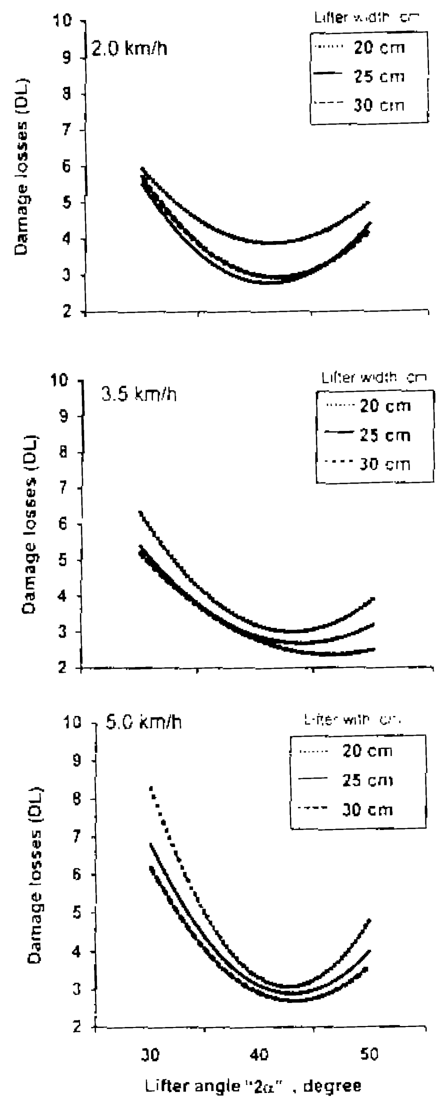




Fig. 8: Lifting efficiency "LE" vs. lifter angle "2α" at different lifter widths and forward speeds "v"

Fig 9 Damage losses "DL" vs lifter angle "2α" at different lifter widths and forward speeds "v"

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**الروى النظرية والحقلية لوحدة مطورة لحصاد بنجر السكر**

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من الدراسة النظرية إتضح أن قيم كل من القوة الأفقية "HF" والقوى الرأسية "VF" تـــزداد تدريجيا بزيادة زاوية إختراق السلاح وكذلك بزيادة عرض السلاح. بينما تأثير عــرض الســلاح على القوة الأفقية أكبر من تأثير زاوية السلاح فى حين تتساوى تقريبا تأثيرها على القوة الرأسـية. أشارت التجارب العملية أن أفضل كفاءة لرفع الدرنات من التربة (٩٨,٥ %) عند زاوية إخــتراق ٢٠ درجة وعرض تشغيل للسلاح ٢٣ سم وسرعة تقدم ٣,٥ كم/ساعة. بينما كانت أقل نسبة تلـف لدرنات بنجر السكر المرفوعة ٢,٥ % عند نفس الظروف السابقة للتشغيل مـــع تغــير عــرض السلاح إلى ٢١ سم. ونظرا لقلة تأثير عرض السلاح المطور على قيم تلف الدرنات لذلك أوصــت الدراسة بعدم إستخدام هذا العرض مع السلاح المطور. بينما أوصت الدراسة باســتخدام ســرعة تشغيل ٣,٥ كم/ساعة وزاوية إختراق ٢٠ درجة مع عرض تشغيل ١٩ سم حيث أعطــت أعلــى كفاءة رفع ٩٧% ونسبة تلف ٢,٢%.