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DEVELOPMENT OF A TOPPING MACHINE TO SUIT MECHANICAL HARVESTING OF SUGAR BEET

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ABSTRACT

In this research work an attempt has been analysed the mechanical performance of a developed machine which can be used to remove the sugar beet leaves in the reclaimed lands before mechanical harvesting operation. The study was carried out in Port-Said Research Station, Port-Said Governorate, during April 2013. Three different speeds of PTO 540, 725 and 1000 rpm, three various forward speeds 0.48, 1.0 and 1.68 m/sec. and three different levels of cutting 3, 6 and 10 cm were conducted to evaluate the machine and assess its mechanical efficiency. Development of this machine aims to avoid spoiling roots during mechanical harvesting. Primary study was carried out to estimate the lost part during traditional topping operation, which shows that the percentage of loss in the weight reached on average 6.2%. The obtained data indicated that PTO speed of 1000 rpm, forward speed of 0.48 m/s and cutting level of 10 cm is the best treatments, which increased the topping efficiency up to 88%.

INTRODUCTION

Sugar beet is one of the most important crops in Egypt grow basically to produce sugar. Other valuable by products remain through the industrial stages of sugar beet. Integrated industries established to use these residues to produce strategic by products such as animal feed. According to the recent annual reports of the Sugar Crops Council, Egypt produces about 2 million tons of sugar and annually consumes about 2.7 million tons. Nowadays, the main sources of sugar production in Egypt are associated with sugarcane (55%), sugar beet (35%), and sweet corn (10%). The planted area of sugar beet has been rapidly increased from about 20,000 feddans on 1980 to about 250,000 feddans on 2000 (EAS, 2011). The rapid increase of the sugar beet area was mainly due to establishing new sugar mills that depend on sugar beet such as Fayoum sugar mill, Nubaria sugar mill and other sugar mills established in the Nile Delta. The importance of sugar beet refers to the fact that producing a ton of sugar from sugar beet need less water compared with that required for sugarcane. Due to the limitation of irrigation water sources, the experts recommended that to overcome the sugar deficiency gap, the area of sugar beet should be increased more than increasing the area of sugarcane.

The farmers of sugar beet suffer from the lack of mechanizing the most exhaustible operations that represented in harvesting and loading sugar beet on the transport vehicles. Sugar beet harvesting consists of sequence of operations represented in sugar beet green top removal (topping), sugar beet roots pulling, cleaning, digging from the soil and collecting at the head of the field.

Topping operation is the most critical operation, as it requires a lot of labor and a lot of effort. Bahnas (2006) mentioned that, loosening and lifting the roots from the soil by 4 laborers per feddan. Removing the vegetative top portion at the desired height and separating the roots from foreign materials by 22 laborers per feddan.

Sugar beet topping is the operation of removing the green leaves before lifting the roots up from the soil. Several references discussed the performance of mechanical toppers such as Raininko (1990); Fuzy and Zule (1984); and Allam *et al.* (1988). If the cut of topping is lower than zero levels (the critical section of cutting), the loss is 1.8 ton/ha, and the percentage of sugar in this part is 10.5 %. If the cut of topping is lower than zero by 1 cm, loss is 3.3 ton/ha, and the percentage of sugar in this part is 16.4 %. Finally if the cut of topping is lower than zero level by 2 cm loss is 3.5 ton/ha and the percentage of sugar in this part is 17.2 %. The topping units are properly adjusted a correct topping ratio of 40 – 50. This may explains the sharp increase in the sugar beet area along the past three decades. Increase speeds (topper forward speed and cutting disc speed) due to decrease topping eff., technical topping eff. and correct topped beet. While, under topped beet, over topped beet and topping losses were increased at both treatments (Tayel *et al.*, 2009).

Mohamed (1998) designed a topper unit to suit small holding. He found that the hardness of beet tuber increase by increase the diameter of beet tuber. Which by increase the beet diameter from (6 cm to 15.6 cm) the hardness of beet increased from (4.09 to 6.02 N/mm^2), respectively.

Abd-Rabou (2004) manufactured a machine used for harvesting sugar beet. He pointed out that the highest value of topping efficiency was 98.1 % at soil moisture content of 22.93 % wb, forward speed of 0.55 m/s, knife speed of 5.89 m/s (450 rpm) and leaves holder speed of 3.53 m/s (225 rpm). While, the lowest value of damage roots was 3.4 % at moisture content of 28.3 % wb, forward speed of 0.55 m/s, leaves holder speed of 2.36 m/s (15 rpm) and knife speed of 5.89 m/s (450 rpm).

Elyamany *et al.*, (2012) mentioned that the maximum value of topping efficiency was 97.9 % which recorded with forward speed of 2.16 km/h (0.6 m/s), topping knife speed of 6.2 m/s and soil moisture content of 18 % w.b. Limitations of the adequate mechanical performance of the sugar beet topping machine was set by Kanafojski and Karwowski (1976) are listed as follow:

1. No more than 5 percent of too high topped or untopped beets.
2. No more than 3 percent of the loss of mass caused by too low topping.
3. No more than 5 percent of the loss of leaves.
4. Admissible contamination of leaves with soil at its moisture content of 16-18 percent up to 1.0 percent.
5. No more than 1.5 percent of un dug roots.
6. Admissible contamination of roots with soil up to 8 percent.
7. No more than 5 percent of heavily damaged root.
8. No more than 1.5 percent of leaves among roots.

The sugar beet companies may import some types of the sugar beet combines to be operated at the large fields in Nubarea and some other newly reclaimed areas. The companies which import these combines, used systems from some Utopian countries to secure obtaining cheep harvesting system for the large areas belongs to the company and those belongs to few rich farmers. This mechanized sector may not exceed 5% of the total production area of sugar beet. The imported sugar beet combines are not the proper machines for the other 95% of the sugar beet production areas. Other types of sugar beet topping and harvesting machines imported from variable industrial sources faces hard problems related to the poor performance efficiency and excessive losses. The locally developed sugar beet harvesting machinery also faces problems related to inconsistency of their parts and mechanisms, poor performance, poor reliability, excessive damage, and excessive losses.

Therefore, the main aim of this work is to develop and evaluate the mechanical performance of sugar beet topper machine.

MATERIALS AND METHODS

This study was carried out in Port-Said Research Station, Port-Said Governorate, during harvesting season of 2013 (during April 2013). The experimental tests done at clay soil texture and the soil specification are listed in table (1). A Top multi germ sugar beet (Gloria variety) was manually planted. The harvesting operation was carried out through soil moisture contents of 21.4 % wb.

Table (1): Soil physical analysis:-

Soil composition, %					Soil texture
			Sand, %		
Clay, %	Silt, %	Clay + Silt, %	Coarse	Fine	
45	26	71	4.1	24.9	Clay

The rotary cultivator specifications

On the base of rotary cultivator, the modification was carried out and the specification of it was done in table (2).

Table (2): The specification of developed rotary cultivator.

Model	MASCHIO, ITALY.
Overall width, cm	190
Rotor diameter, cm	40
Weight, kg	300
Diameters of trans- mission gears, mm	117 / 163

The developed sugar beet topper machine

The developed sugar beet topper machine was locally fabricated as shown in Figs. (1) and (2). It consists of main three parts: frame, horizontal rotary shaft and sets of rectangular rubber strippers, installed in circular rings located around the shaft and fixed using quadrants and clamps. The stripper gross dimensions are 20 cm long, 8 cm wide and 1 cm thick. The hardness of rubber strippers was 10 N/mm^2). These rubber strippers operate in a longitudinal manner. These rubber strippers could remove the leaves from the roots completely without damage of the beets.

Fig. (1): The developed sugar beet topper machine.

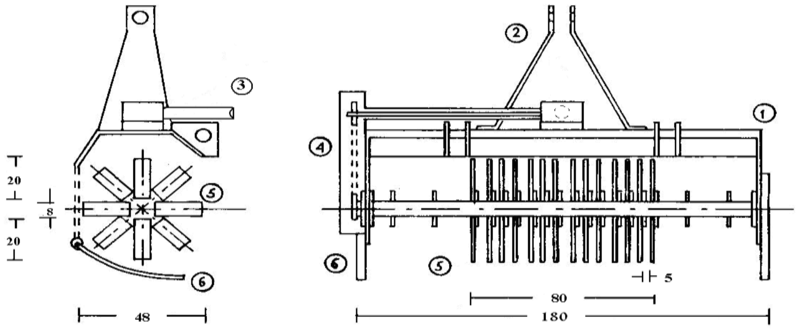

Fig. (2): Schematic diagram of the developed sugar beet topper machine (Dims in cm.).

(1) Main frame,	**(2) Three-point linkage,**
(3) Power take-off,	**(4) Power transmission unit,**
(5) Rubber strippers, and	**(6) Topping level mechanism.**

Fig. (3) shows sugar beet after topping operation without any scratch or any damage. The overall width of the machine is 180 cm; and the effective width is 80 cm.

Properties of sugar beet

Some physical and mechanical properties of sugar beet are summarized and listed in Table (3) according to Kromer, *et al.* (2004):

Table (3): Some properties of sugar beet.

Physical properties:	Range	Mechanical properties:	Range
Length, mm		Coefficient of friction	0.22– 0.7
- beet	72 – 350	Pressure required to separate leaves from beet, N/mm^2	0.25 - 0.5
- leaves	100 – 750	Pressure that causes damages of epidermis, N/mm^2	3 - 4
Diameter, mm	40 –170	Coefficient of elasticity	2.81 - 3.36
Mass, g	150 - 1800		
Density, kg/m^3	1000 - 1150		
Bulk density, kg/m^3	520 – 600		

Fig. (3): Sugar beet after topping operation.

Tractor specifications

The main of experimental tractor specification were, model of YANMAR F-42ex – diesel, diesel engine, 4 wheel drive, max. engine output of 31.34 Kw and rear PTO of 540 / 725 / 1000 rpm at 2700 Engine rpm. Measured fuel consumption rate was 4 l/h (according to the local calibration in agricultural mechanical station of Port Said).

Investigated variables

Tractor forward speed: three different forward speed levels 0.48, 1.0 and 1.65m/s.

Topping speed: three various PTO levels 1000, 725 and 540 rpm.

Topping level: three different topping levels 3, 6 and 10 cm.

Sugar beet planting method

Manual method, using the conventional method. The rows spacing and the hills spacing in the same row were almost adjusted to be 40 cm and 20 cm, respectively.

Harvesting methods

Harvesting operation has been applied in two stages as follows:

1-Removing the vegetative tops: this stage was carried out using the developed topper machine.

2-Lifting and cleaning sugar beets: this stage was carried out traditionally by hand digging, pulling the roots out by shovel and hoe and collecting the roots manually.

Traditional method

The traditional (manual) harvest method was carried out as follows:

1- Lifting the roots from the soil by 4 labors per feddan.

2- Removing the vegetative top portion at the desired height and separating the roots from foreign materials by 15 labors per feddan.

In both the mechanical and the traditional harvest methods, a team of 4 labors per feddan. carried out the clean beets consolidation out-side the field and conducted the beets deposition in a track.

Soil moisture content

Soil moisture content can be determined using the following formula:

$$MC = [(m_1 - m_2) / m_1] \times 100 \quad \ldots\ldots (1)$$

Where:

M.C = Moisture content, %, wb.

m_1 = Sample mass before drying, g.

m_2 = Sample mass after drying, g.

Topping efficiency

Topping efficiency, technical topping efficiency, correct topped, and broken beets were assessed in a percentage as an indicator for the mechanical topper performance. The above independent variables were calculated using the following formulas:

$$\text{Topping efficiency (\%)} = (N_t / N_T) \times 100 \quad \ldots\ldots (2)$$

$$\text{Damage (\%)} = (N_d / N_t) \times 100 \quad \ldots\ldots (3)$$

Where:

N_t = Topped beet mass, kg

N_T = Total beet mass, kg

N_d = Scarified beet mass, kg.

Energy requirements

Specific machine energy requirements, (SME): it is estimated according to Bahnas, (2006) and many others as follows:

$$SME = (11.41 \times FC) / AFC \quad \text{MJ / fed.} \quad \ldots\ldots (4)$$

Where:

FC = the fuel consumption, l/h.

11.41 = the transformation coefficient.

AFC = the actual field capacity, fed/h.

Where:

$$AFC = 1 / ATT \quad \text{fed/hr} \quad \ldots\ldots (5)$$

Where:

ATT is the actual total time in hours required per feddan.

Traditional sugar beet harvest method cost

During the manual harvesting operation of sugar beet, the salary per day for the labor was 30 LE.

Mechanical sugar beet harvest method cost

According to the rental value of the YANMAR tractor from the mechanical station of Port Said was 30 LE/h. during topping operation.

Statistical analysis of data

All the charts were obtained using Microsoft Excel software (2003). All obtained data was analyzed statistically by using a computer program (MINITAB) for estimating regression equations and coefficient of determination (R^2).

RESULTS AND DISCUSSION

Topping efficiency

Fig. (4) shows the effect of forward speeds with three different speeds (0.48, 1.0 and 1.65 m/s) and different cutting levels of the topper (3, 6 and 10 cm) on mechanical topping efficiency with the rotational speed of PTO 540 rpm of the rubber strippers.

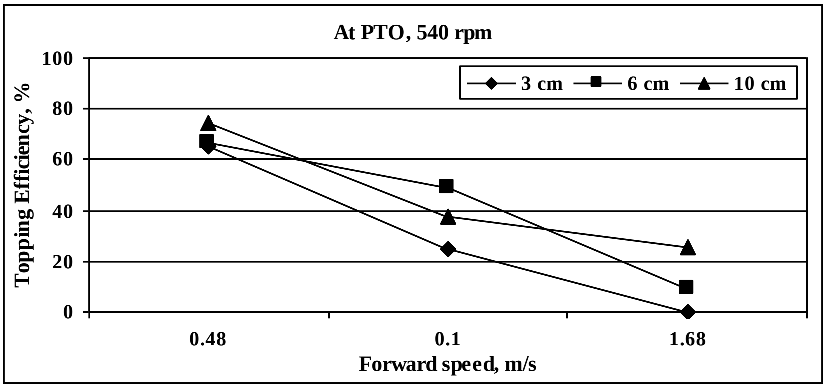

Fig. (4): Mechanical topping efficiency of the topper machine at different forward speeds and different cutting levels with PTO 540 rpm.

The mechanical topping efficiency which recorded during mechanical tests was 74.12, 37.7 and 25.27 % at cutting level of 10 cm, and forward speeds of 0.48, 1.0 and 1.68 m/s, respectively. Whereas the mechanical topping efficiency was 66.70, 49.03 and 8.97 % at depth of 6 cm and forward speeds of 0.48, 1.0 and 1.68 m/s, respectively. While, the mechanical topping efficiency was 65.31, 24.51 and 0.00 % at cutting level of 3 cm and forward speeds of 0.48, 1.0 and 1.68 m/s, respectively.

Results presented in Fig. (5) show the effect of different forward speeds and different cutting levels on the mechanical topping efficiency with rotation speed of 725 rpm.

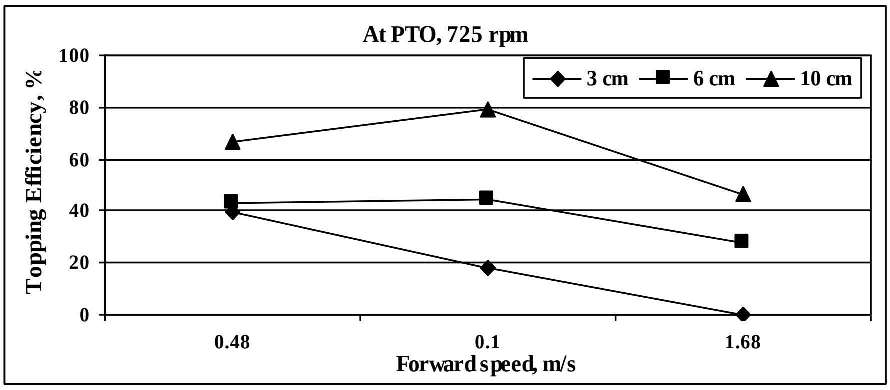

Fig. (5): Mechanical topping efficiency of the topper machine at different forward speeds and different cutting levels with PTO 725 rpm.

Fig. (5) also demonstrates that the mechanical topping efficiency was 39.39, 18.23 and 0.00 % at cutting level of 3 cm and forward speeds of 0.48, 1.0 and 1.68 m/s, respectively. While the mechanical topping efficiency was 43.33, 44.48 and 27.94 % at cutting level of 6 cm and forward speeds of 0.48, 1.0 and 1.65 m/s, respectively. Whereas, the mechanical topping efficiency was 66.52, 78.92 and 46.50 % at cutting level of 10 cm and forward speeds of 0.48, 1.0 and 1.68 m/s, respectively.

The plotted data in Fig. (6) reveal the effect of different forward speeds and different cutting levels on the mechanical topping efficiency with rotation speed of 1000 rpm.

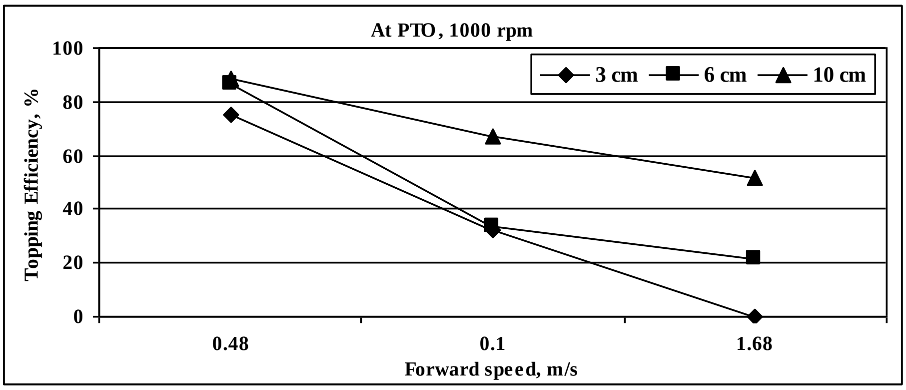

Fig. (6): Mechanical topping efficiency of the topper machine at different forward speeds and different cutting levels with PTO 1000 rpm.

It clearly shows that the mechanical topping efficiency of 75.45, 32.41 and 0.00 % was achieved at cutting level of 3 cm and forward speeds of 0.48, 1.0 and 1.65 m/s, respectively. Whereas the mechanical topping efficiency was 86.35, 33.41 and 21.75 % at cutting level of 6 cm and forward speeds of 0.48, 1.0 and 1.68 m/s, respectively. Whereas, the mechanical topping efficiency was 88.38, 67.21 and 51.66 % at cutting level of 10 cm and forward speeds of 0.48, 1.0 and 1.68 m/s, respectively.

Consequently, the greatest mechanical topping efficiency (88.38 %) achieved at the highest levels of (10 cm) with the lowest forward speed (0.48 m/s) and with the highest rotational speeds of PTO 1000 rpm.

Figs (4), (5) and (6) also reveal that the lowest levels of cutting and the highest values of forward speed given the lowest values of mechanical topping efficiency. The highest forward speeds are not given the opportunity to cut the leaves of beets. Also, the same result occurs due to the lowest levels of cutting.

To assess the most important parameters affecting the mechanical topping efficiency during topping operation, the rotational speed of PTO, forward speed and cutting level, were used to examine their relationships with mechanical topping efficiency. The multiple regression equation for the best fit (with coefficient of determination, $R^2 = 0.8717$) was:

Mechanical topping efficiency % = 36.4 + 0.0262 (PTO, rpm)
- 38.9 (forward speed, m/s) + 4.46 (cutting level, cm).

Multiple regression analysis revealed a highly significant linear relationship, ($r = 0.9337$; $P \leq 0.001$). The previous regression equation also revealed that, the mechanical topping efficiency was inversely proportional to forward speed and directly proportional to the cutting level and PTO rotation speed.

Mechanical beet damage

Fig. (7) explains the effect of different forward speeds (0.48, 1.0 and 1.65 m/s) and three different cutting levels of the topper machine (3, 6 and 10 cm) with a rotational speed of 540 rpm on the percentage of damage.

As clearly shown in Fig. (7) no damage (0.0 %) occurred at a level of 10 cm, while the damage increases with decrease in cutting level. The damage was 6.03, 9.23 and 9.8 % at level of 3 cm and forward speed of 1.68, 1.0 and 0.48 m/s, respectively.

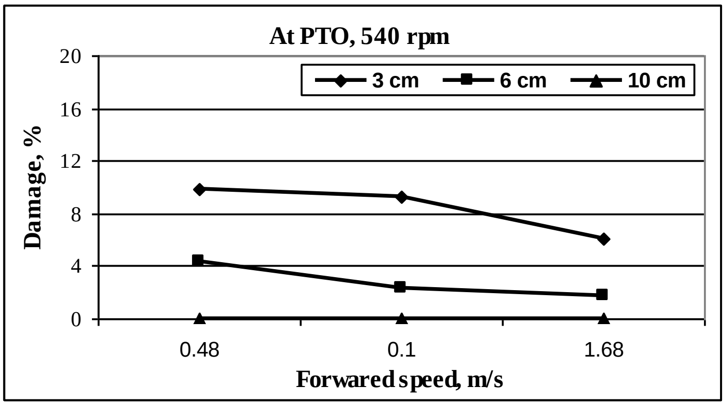

Fig. (7): Mechanical beet damage of the topper machine at different forward speeds and different cutting levels with PTO 540 rpm.

Fig. (8) reveals the effect of different forward speeds (0.48, 1.0 and 1.65 m/s) and three different levels of cutting level of the topper (3, 6 and 10 cm) with a rotational speed of PTO 725 rpm on the percentage of damage.

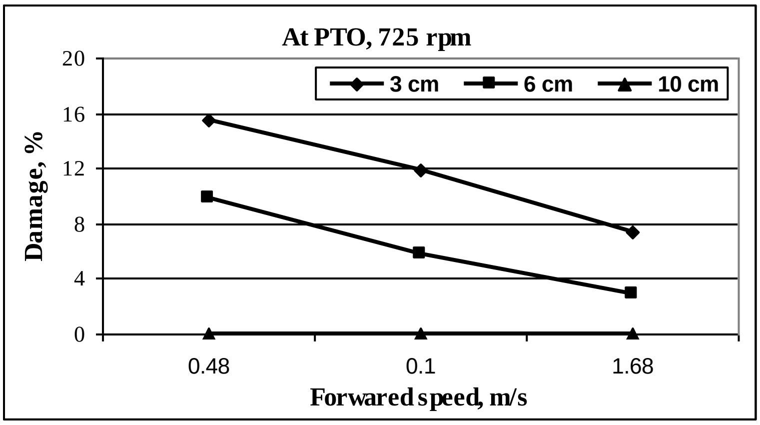

Fig. (8): Mechanical beet damage of the topper machine at different forward speeds and different cutting levels at PTO 725 rpm.

Fig. (8) also shows no damage (0.0 %) occurred at a cutting level of 10 cm, while the damage increases with decrease in cutting level. The maximum damage was 7.43, 11.87 and 15.52 % at cutting level of 3 cm and forward speeds of 1.68, 1.0 and 0.48 m/s, respectively.

Fig. (9) demonstrates the effect of different forward speeds (0.48, 1.0 and 1.65 m/s) and three different levels of cutting of the topper (3, 6 and 10 cm) with a rotational speed of PTO 1000 rpm on the percentage of damage.

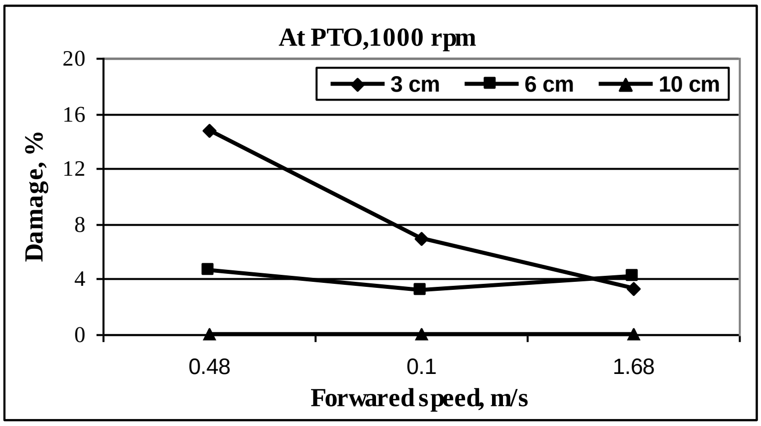

Fig. (9): Mechanical beet damage of the topper machine at different forward speeds and different cutting levels with PTO 1000 rpm.

As shown in Fig. (9) there is no damage (0.0 %) occurred at a cutting level of 10 cm, while the damage increases with decrease in cutting level. The damage was 3.29, 6.92 and 14.73 % at cutting level of 3 cm and forward speeds of 1.68, 1.0 and 0.48 m/s, respectively. Figs. (7), (8) and (9) showed that, the topping operation without any damage occurred in the circumstances of cutting level of 10 cm with different forward speeds. They also revealed that, the mechanical beet damage increases with reduced cutting levels. This observation may be due to the higher impact forces between rubber strippers and the beet, resulting in more beet scarification.

To assess the most important parameters affecting the percentage of damage during topping operation, the rotational speed of PTO, forward speed and cutting level, were used to examine their relationships with the percentage of damage. The multiple regression equation for the best fit, with coefficient of determination, $R^2 = 0.897$ was:

Damage % = 14.9 + 0.00028 (PTO, rpm) - 3.05 (forward speed, m/s) - 1.33 (cutting level, cm)

Multiple regression analysis revealed a highly significant linear relationship, ($r = 0.9471$; $P \leq 0.001$). The previous regression equation also revealed that, the topping mechanical efficiency was inversely proportional to forward speed and directly proportional to cutting level and PTO rotation speed.

Actual field capacity

The results have shown the effect of forward speed on actual field capacity. The actual field capacities were 0.31, 0.68 and 1.14 fed/h. at forward speeds of 0.48, 1.0 and 1.65 m/s, respectively.

Machine operational cost

The actual cost of topping operation was as following:

a. The mean value of topping operational cost was 96.77 LE/fed.

b. Lifting (manual) of the roots from the soil was 120 LE/fed.

c. Cleaning (manual) of the sugar beet outside the field and deposition in a factory track was 120 LE/fed.

Then, the total costs of topping operation, lifting and cleaning were 336.77 LE/fed.

Traditional sugar beet harvest method cost

Data of the traditional sugar beet harvest method could be presented as follows:

a. Manual loosening and lifting of the roots from the soil is 120 LE/fed.

b. Removing the vegetative top portion (topping) manually is 450 LE/fed.

c. Cleaning (manual) of the sugar beet outside the field and deposition in a factory track was 120 LE/fed.

Then, the total costs of topping operation, lifting and cleaning were 690 LE/fed.

Energy requirements

The obtained data also show the effect of machine field capacity on energy requirements. The energy requirements were 147.23, 67.12 and 40.04 MJ/fed at actual field capacities of 0.31, 0.68 and 1.14 fed/h, respectively.

CONCLUSION

The obtained results of this study could be concluded as follows:

1- The highest value of topping mechanical efficiency of (88.38 %) attained at highest cutting level of (10 cm) with lowest forward speed of (0.48 m/s) and highest rotational speed of (1000 rpm).

2- Lowest level of cutting and highest value of forward speed had given the lowest value of topping mechanical efficiency. The highest forward speed was not given the opportunity to cut the leaves of beets. Also, the same result occurred due to the lowest level of cutting.

3- The topping operation without any damage that have been occurred in the circumstances of cutting level of (10 cm) at different forward speeds. The beet mechanical damage increases with reduced cutting level.

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تطوير آلة لتطويش بنجر السكر قبل الحصاد الميكانيكى

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تهدف الدراسة الى تطوير آلة مبسطة لتطويش نباتات بنجر السكر وهو المحصول الذى يكثر زراعتة بمناطق شرق الدلتا حيث الاراضى الملحية الثقيل التى لا تصلح لزراعة المحاصيل الحقلية التقليدية والتى تحتاج للتربة الجيدة.
واثبتت الالة صلاحيتها للعمل ، حيث وصلت كفائتها فى عملية التطويش لأكثر من ٨٨ % وبجودة تطويش عالية وبدون ان تصيب الدرنات بأى تلف أو ضرر، بخلاف ما يحدث أثناء إجراء عملية التطويش يدوياً، حيث يتم قطع جزء من الدرنات أثناء التطويش اليدوى باستخدام الالات الحادة وقد يصل الفقد فى وزن المحصول الى حوالى ٥ – ٩ % من الوزن الكلى للمحصول وهذا لا يحدث عند استخدام الالة المطورة .
أثبتت التجربة أن هناك علاقة عكسية بين الكفاءة الميكانيكية للتطويش والسرعة الامامية للجرار ، وعلاقة طردية بين الكفاءة الميكانيكية للتطويش وعمق التطويش. أيضاً أثبتت التجربة ان استخدام الالة عند سرعة أمامية ٠.٤٥ م / ث وعند سرعة دوران لعمود الادارة الخلفى ١٠٠٠ لفة / دقيقة (١٠.٤٧ م/ث) وعمق التطويش ١٠ سم يعطى أعلى كفاءة تطويش , وبدون حدوث اى خدش للدرنات ووصلت كفاءة التطويش الى ٨٨.٣٨ % .

قام بتحكيم البحث

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