# Development of suitable potato crop harvester for small holdings

Gamal El-Din Mohamed Nasr[1], Mohamed Nagiub Rostom[1], Mohamed Morsy Mohamed Hussein[2], Ahmed El-Fateh Farrag[3], Maher Fathy Attia Morsy[2*]

(1. *Agric. Eng., Agric. Eng. Dept., Fac. Agric., Cairo Univ.*;
2. *Water relation and field irrigation Dept., Agric. Division, National Research Centre, Egypt*;
3. *Mechanical Eng. Dept., Eng. Division, National Research Centre, Egypt*)

**Abstract:** Potato crop (Solanum tuberosum) in Egypt is one of the major vegetable crops, as it is grown each year, cultivated area is 183702 ha, and quantity of production is 4955445 ton. The farming structure in Egypt has totally changed during the past 50 years. It has gone from a small number of very large holdings to very large number of small holdings. The main objectives of this research were to develop, manufacture and evaluate self propelled potato harvesting machine suitable for small holdings. The develop and manufacture of the self propelled machine were conducted at the Agricultural Engineering Department, Faculty of Agriculture, Cairo University and small workshop in Al-Aiyat town, Giza Governorate Egypt and the soil texture was found to be almost clay loam. A potato harvester self propelled machine (single row) was designed, developed, manufactured and evaluated. The developed self-propelled machine was evaluated at three levels of forward working speed (1.5, 2.0 and 2.5 km $h^{-1}$) and three levels of digging depth (16, 20 and 24 cm). Evaluation was depended on the following parameters: machine field capacity, harvesting efficiency, damaged potato tubers, consumed energy and cost of harvesting operation. The percentage of damaged potato tubers increased by accelerated the forward speed from 1.5-2.5 km $h^{-1}$, but damaged percent decreased with increasing the digging depth. The highest value of field capacity was at operating speed of 2.5 km $h^{-1}$. The highest harvesting efficiency was at the digging depth of 24 cm and operating speed of 1.5 km $h^{-1}$. The harvesting efficiency decreased by increasing the forward speed from 1.5 to 2.5 km $h^{-1}$ at different digging depths, the lowest value of the consumed energy was found at the digging depth of 16 cm and operating speed of 1.5 km $h^{-1}$, the consumed energy increased with increasing digging depth. The highest value of the missing tubers percentages was at the digging depth 16 cm and operating speed 1.5 km $h^{-1}$. By increasing the digging depth the missing tuber decreased. The minimum costs were found at digging depth of 16 cm and operating speed 2 km $h^{-1}$. The lowest value of harvesting time was by using of the self propelled machine comparing to manual harvesting and traditional plough. While the harvesting time decreased to 25% and 30% comparing to manual harvesting time and traditional plough respectively. The harvesting costs value of the self-propelled machine was 34$ $ha^{-1}$ According to 2017, so, it was decreased by about 31.25% and 62.5 % comparing to manual harvesting costs and traditional plough respectively.

**Keywords:** potato, self propelled, develop, tubers damage, smallholding

**Citation:** Nasr, G. E., M. N. Rostom, M. M. Hussein, A. E. Farrag, and M. F. Morsy. 2019. Development of suitable potato crop harvester for small holdings. Agricultural Engineering International: CIGR Journal, 21(2): 34–39.

## 1 Introduction

Potato (*Solanum tuberosum*) occupies an important place among food crops in many countries of the world, as in terms of nutritional value, it is the first alternative to cereal crops in solving the food problem (Horton and Sawyer, 1985). The quality of potato tubers is closely connected to the physical and chemical characteristics of plant tissues and varies also in other factors such as climate, growing conditions, cultivar and maturity at harvest time and harvesting method (Bentini et al., 2006).

Harvesting potato crop is a very important part of the potato production and marketing operation. Damage occurs during digging, loading, and transporting operations. The damage resulting of impact on tubers during harvesting operations alone may cause losses in excess of 20% (Storey and Davies, 1992). During harvesting and transporting the potato crop, potato tubers

**Received date:** 2018-02-11 **Accepted date:** 2018-08-15

***Corresponding author: Maher Fathy Morsy,** Institute: National Research Centre, Address: 33 El-Behoose St., Dokki, Egypt. Tel: +201151811616, Email: maher_fathi1980@yahoo.com

are exposed to damage which ranges from internal black spot, shatter bruising and tissue cracking (Mathew and Hyde, 1997). Egyptian agriculture is characterized by a large base of very small holders of less than 0.8 h, referred to by the World Bank as poor holders, whose holdings represent about 66.35 % of the total number of holdings (FAO, 2010).

Nasr (1992) mentioned that there were many components on the digger as compared to the spinner. These components come in contact with the soil and this inevitably means that more wear can take place. He added that one main advantage of the elevator digger over the spinner was that it deposited the crop in a narrow row on the field and this eases considerably the work of the hand pickers. The complete harvester digs, separates and delivers into sacks, boxes or trailers during one path of the machine over the field. In fact the range of complete harvesters available can be classified into manned, and unmanned. The main objectives of this research were to develop, manufacture and evaluate the self-propelled suitable Potato harvesting machine for small holdings under Egyptian agricultural conditions.

## 2 Materials and methods

The soil texture was found to be almost clay loam, and samples of soil were analysed in the laboratory of soil science department, National research centre. The develop and manufacture of the self propelled machine were conducted at the Agricultural Engineering Department, Faculty of Agriculture, Cairo University and small workshop in Al-Aiyat town, Giza Governorate, Egypt.

### 2.1 Self-propelled machine parts

**a. Power source selection:** several alternatives of the power source were selected according to the following steps for the determination of the required power source:

Power requirement

$$\text{Tensile force (kg)} = \text{Operating width (cm)} \times \text{Digging depth (cm)} \times \text{Soil specific resistance (kg cm}^{-2}) \quad (1)$$

$$\text{Tesile power (hp)} = \frac{\text{Tensile force (kg)} * \text{Forward speed (km h}^{-1})}{270} \quad (2)$$

$$\text{Brake horse power for tractor (hp)} = \frac{\text{Tensile power (hp)}}{\text{Total efficiency of transmissions (\%)}} \quad (3)$$

(Field and Solie, 2007)

**b. The blade.**

Blade was designed to cut the soil, free up the potato from the soil, and elevate it to the separator.

The blade was made using steel 50, by a width of 59 cm to suit the harvest only one line to harvest potatoes.

**c. The separator.**

Separator rods

The diameter of rods *dr* and clearance between the rods *Sr* can be calculated by the following equations:

$$Sr - dr \le dp \quad (4)$$

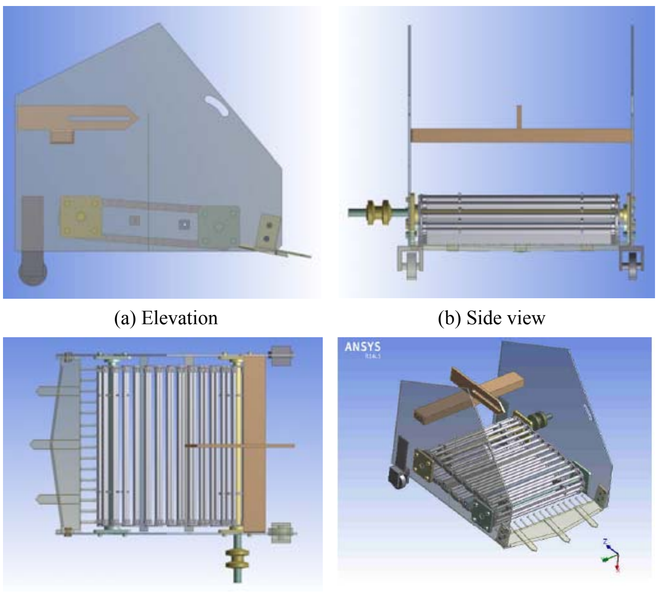
where, *Sr*: The distance between rods = 30 mm; *dr*: The diameter of rods = 10 mm; *dp*: The diameter of tuber = 35 mm.

$$dp = \sqrt[3]{LWT} \quad (5)$$

where, *L*: is the tuber length (mm); *W*: is the tuber width (mm); *T*: is the tuber thickness (mm).#

**Separator shafts:**

Design equations were used to determine the diameter of separator shafts and determining the specifications of bearing according to the separator shaft diameter showed in Budynas and Nisbett (2006). Figure (1) shows the final form of the self propelled potato harvesting machine.

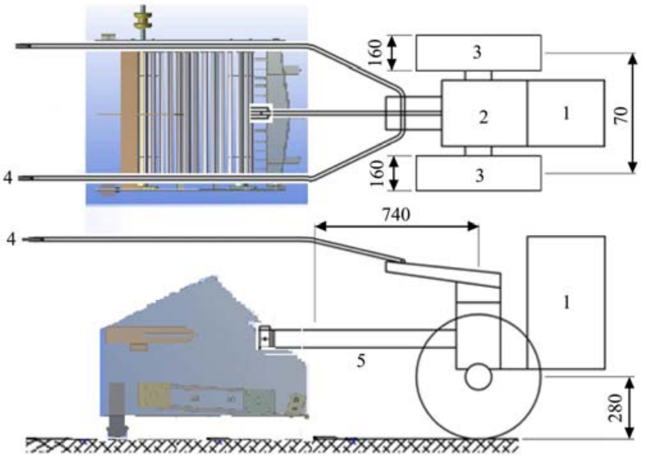


(a) Elevation (b) Side view

(c) Plan view (d) Isometric

Figure 1 Isometric and three views for final self propelled potato harvesting machine

The selected used power source was with specifications as follow: 12 hp (8.8 kW) engine power. Gasoline engine, speed (1st gear: 1.5 km $h^{-1}$ - 2nd gear: 2 km $h^{-1}$ - 3rd gear: 2.5 km $h^{-1}$ - Reverse: 2.0 km $h^{-1}$). Also, it is possible to use the small power tractors from 12 to 16 hp, and this kind of tractors is very popular in many Egyptian governorates. The small tractors (12:16 hp) could be locally manufactured such as assembling the available power source (12 hp motor) with small gear box on a chassis to the power source for harvesting process.




1. Engine 2. Gear box 3. Driven wheel 4. Handle steering 5. Machine beam holder

Figure 2 Plan and elevation views for final self propelled potato harvesting machine

## 2.2 Evaluation of the machine

The measurements were followed according to Stout and Cheze (1999). The harvesting investigations were conducted using three different levels of digging depth of 16, 20 and 24 cm at three different forward speeds of 1.5, 2.0 and 2.5 km $h^{-1}$.

2.2.1 Potato crop damage percent ($D_t$ %)

In order to determine the damage percentage the following equation was used. The mass of potato crop ($m_c$) is for tubers which have no bruise or cutting for each of the mentioned samples, and the mass of damaged potato crop ($m_d$) had only serious damage or neglected slight damage. The damaged tubers percent could be determined using the following formula:

$$D_t = \frac{m_d}{m_c + m_d} \times 100 \qquad (6)$$

where, $m_d$: The mass of damaged potato crop (kg); $m_c$: The mass of undamaged potato crop (kg).

2.2.2 Machine field capacity

The potato harvester field capacity was calculated from the following equation:

$$FC = A/(t_p + t_i) \qquad (7)$$

where, $FC$: Effective field capacity (fed $h^{-1}$); $A$: Performed area (fed.); $t_p$: Productive time (h); $t_l$: Non-productive time (h).

2.2.3 Lifted potato crop percentage

After the harvesting operation was done for the experimental groups, potato tubers over the soil surface were collected; also the unlifted potato tubers were manually harvested by hand. The lifted potato crops percentage ($lift_t$ %) were determined from the following

$$lift_t = \frac{m_1}{m_1 + m_2} \times 100 \qquad (8)$$

where, $m_1$: The weight of lifted potato over soil surface (kg); $m_2$: The weight of unlifted potato (kg).

2.2.4 Harvesting efficiency

The harvesting efficiency ($\eta_H$ %) was calculating according to the following equation:

$$\eta_H = \frac{m_1 - m_4}{m_1} \times 100 \qquad (9)$$

where, $m_1$: The weight of lifted potato over soil surface (kg); $m_4$: The weight of damaged potato tubers (kg).

2.2.5 Fuel consumption

The tank is filled to full capacity before and after each test trial. Amount of refuelling after the test is the fuel consumption for the test. When filling up the tank, careful attention should be paid to keep the tank horizontal and not to leave empty space in the tank.

$$F = \frac{V}{T} \qquad (10)$$

where, $F$: Fuel consumption, (L $h^{-1}$); $V$: Volume of fuel consumed, (L); $T$: Total operating time, (h).

2.2.6 Energy consumption

$$\text{Energy} = \frac{\text{Required power (kW)}}{\text{Eff. field capacity (fed h}^{-1})} = \text{kW h fed}^{-1} \qquad (11)$$

2.2.7 Operation costs

The machine operating costs were calculated from the following equation. The cost was based on the initial cost of machine, interest on capital, cost of fuel and oil consumed, cost maintenance and cost of labour.

$$C = \frac{P}{H}\left(\frac{1}{y} + \frac{i}{2} + t + m\right) + (A.K.f.u) + \frac{s}{h} \qquad (12)$$

Cool, et al. (1991)

where, $C$: Total hourly cost (LE $h^{-1}$); $P$: Initial price or capital of tractor or machinery (LE); $H$: Estimated yearly hours of operation (N); $Y$: Estimated life-expectancy of machines in years (year); *I*: Annual interest rate (%); *T*: Taxes and overhead rates (%); *M*: Maintenance and repairs ratio to capital head (LE); *K*: Engine power (kW or hp); *A*: Ratio of rated power and lubrication related to fuel cost (0.8); *F*: Specific fuel-consumption (L $kW^{-1}$ $h^{-1}$ or L $hp^{-1}$ $h^{-1}$); *U*: Price of fuel per L (LE $litre^{-1}$); *S*: Monthly wages or salaries (LE); *H*: Estimated working hours per month (h).

### 2.3 Treatments

| Variable | Value |
|---|---|
| Forward speed (km $h^{-1}$). | 1.5, 2, and 2.5 |
| Digging depth (cm). | 16, 20 and 24 |

## 3 Results and discussion

The field experiment were conducted at El-Beleda village, AL-Aiyat town, Giza Governorate, Egypt. Results showed as follow.

### 3.1 Effect of forward speed and digging depth treatments on the damaged potato tubers percentage

Results revealed that the damaged tubers percentage increased by accelerating the forward speed as shown in the figure 3. Also the tubers damaged percentage ($D_t$ %) decreased by the increase of digging depth. The percentage of damaged tubers was increased by increasing the speed from 1.5-2.5 km $h^{-1}$ due to the friction between the blade and tuber, but the damage percent decreased with increasing the digging depth. The maximum value of damaged tuber was 8 % at forward speed of 2.5 km $h^{-1}$ and digging depth of 20 cm, while the minimum value was 3.4 % at forward speed of 1.5 km $h^{-1}$ and digging depth of 24 cm.

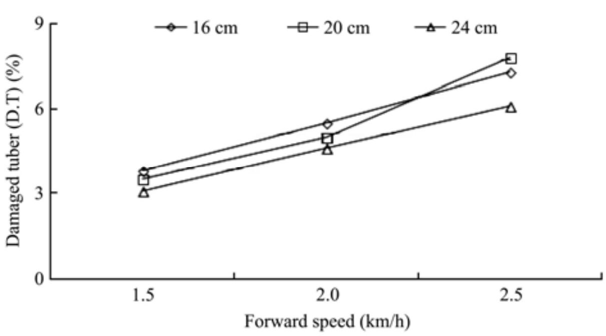



Figure 3 Effect of forward speed and digging depth treatments on the damaged tubers percentage

### 3.2 Effect of forward speed and digging depth treatments on the field capacity (ha $h^{-1}$)

Results showed that the highest value of field capacity was at digging depth of 24 cm and operating speed of 2.5 km $h^{-1}$, as shown in Figure 4. The field capacity was affected directly by operating conditions speed and digging depth. From obtained data in Figure 4, It is clear that the digger felid capacity increased by increasing the forward speed from 1.5 to 2.5 km $h^{-1}$. On the other hand, felid capacity decreased by increasing the digging depth due to increased force with increasing the depth. The maximum value of the field capacity was 0.952 ha $h^{-1}$ at forward speed of 2.5 km $h^{-1}$ and digging depth of 16 cm, while the minimum value was 0.476 ha $h^{-1}$ at forward speed of 1.5 km $h^{-1}$ and digging depth of 24 cm.

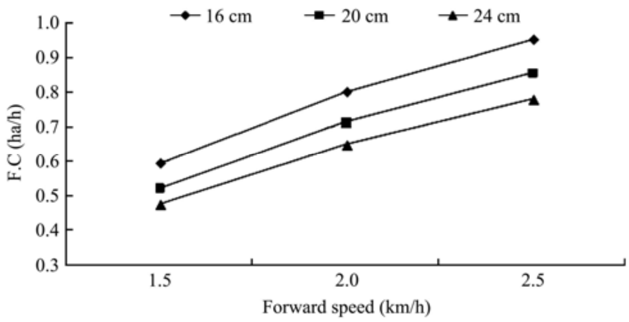



Figure 4 Effect of forward speed and digging depth treatments on the field capacity (ha $h^{-1}$)

### 3.3 Effect of forward speed and digging depth treatments on harvest efficiency (%)

Results showed that the highest value of harvesting efficiency at the digging depth of 24 cm and forward speed 1.5 km $h^{-1}$. As shown in Figure 5, the harvester efficiency is related with the raised, damaged, undamaged and left tubers. Figure 5 showed harvester efficiency decreased by increasing the speed from 1.5 to 2.5 km $h^{-1}$ with different digging depths of 16, 20, and 24 cm. The maximum value of harvester efficiency was 98.75% at forward speed of 1.5 km $h^{-1}$ and digging depth of 24 cm, while the minimum value was 65.8% at forward speed of 2.5 km $h^{-1}$ and digging depth of 16 cm.

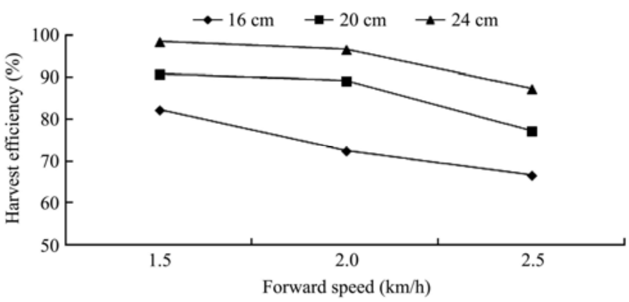



Figure 5 Effect of forward speed and digging depth treatments on Harvest efficiency (%)

### 3.4 Effect of forward speed and digging depth treatments on consumed energy (kW h ha$^{-1}$)

Results showed that the lowest value of the consumed energy was found at the digging depth of 16 cm and forward speed of 1.5 km h$^{-1}$. As shown in figure 6, the energy is affected directly by the forward speed and field capacity. Referring to Figure 6, the consumed energy was reduced in the speed range 1.5 to 2.0 km h$^{-1}$ due to the corresponding of increase the field capacity. After that, energy increased with speed change from 2.0 to 2.5 km h$^{-1}$ due to decreased field capacity. On the other hand energy increased with increasing digging depth due to increasing the required power to overcome the higher resistance of the soil at deeper depths.

The maximum value of consumed energy was 58.33 kW·h/ha at forward speed of 2.5 km h$^{-1}$ and digging depth of 24 cm, while the minimum value was 22.38 kW·h/ha at forward speed of 1.5 km h$^{-1}$ and digging depth of 16 cm.

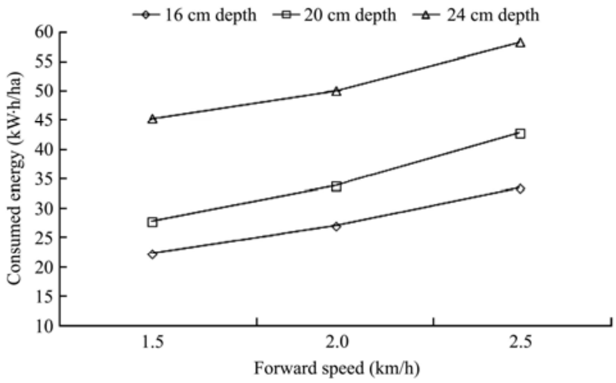



Figure 6 Effect of forward speed and digging depth treatments on consumed energy (kW h ha$^{-1}$)

### 3.5 Effect of forward speed and digging depth treatments on missing tuber (%)

It was found that the highest value of the missing tubers percentages at the digging depth of 16 cm and forward speed 1.5 km h$^{-1}$. As shown in Figure 7, the percentage of missing tubers decreased with increasing the speed from 1.5 km h$^{-1}$ to 2.5 km h$^{-1}$. It was noticed that with increasing the digging depth, the missing tubers decreased due to the distance between the top of the line and the lowest point of the tubers ranging from 16 to 24 cm. The maximum value of missing tubers was 2.75 % at forward speed of 1.5 km h$^{-1}$ and digging depth of 16 cm, while the minimum value was 1.1 % at forward speed of 2.5 km h$^{-1}$ and digging depth of 24 cm (Figure 7).

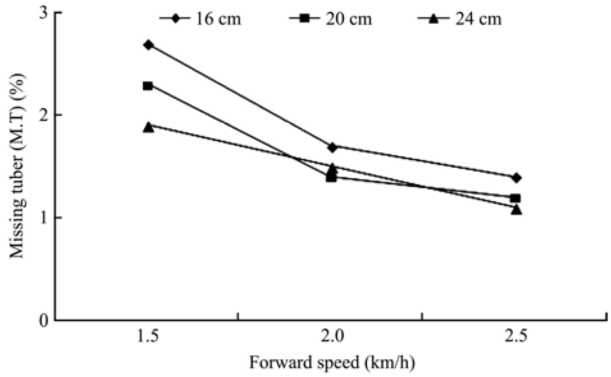



Figure 7 Effect of forward speed and digging depth treatments on missing tuber (%)

### 3.6 Effect of forward speed and digging depth treatments on cost ($ ha$^{-1}$)

Results showed that the minimum value of cost were found at digging depth of 16 cm and forward speed 2 km h$^{-1}$. As shown in Figure 8, the maximum value of cost was 34$ ha$^{-1}$ at forward speed of 1.5 km h$^{-1}$ and digging depth of 24 cm, while the minimum value was 27 $ ha$^{-1}$ at forward speed of 2 km h$^{-1}$ and digging depth of 16 cm.

As a result of this study, it is recommended to use the following operating variables: 2.5 km h$^{-1}$ speed and 24 cm depth. The evaluation parameters were field capacity of 0.781 ha h$^{-1}$, harvesting efficiency of 98.75%, missing tubers of 1.8%, damaged tubers of 3.4%, consumed energy of 45 kW h ha$^{-1}$ and cost 34$ ha$^{-1}$.

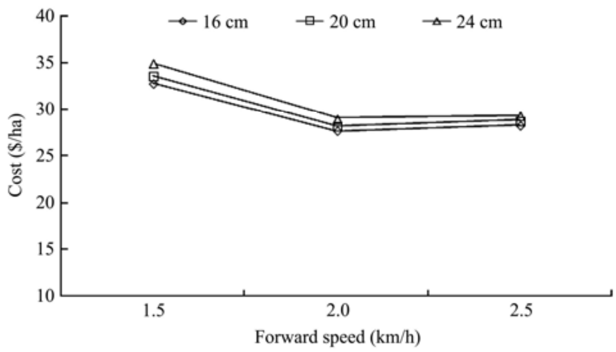



Figure 8 Effect of forward speed and digging depth treatments on cost ($ ha$^{-1}$)

### 3.7 Comparison of the different harvesting methods

A comparison field experiments between the different harvesting methods (self-propelled machine, traditional plough and manual) was performed. Comparing the man power, time and costs required developed machine with the commonly practiced methods of potato harvesting positive results were obtained in favor of the developed machine. From Figure 9, potato harvesting times for one hectare by the manual, local plough and developed machine were 21, 16 and 5.9 hours respectively. The harvesting time decreased to 25%, 30% comparing to manual harvesting time and traditional plough respectively and Figure 10 showed that the harvesting costs for one hectare with different methods were 108.8, 54.4 and 34$ (according to 2017 local conditions). The harvesting cost decreased by about 31.25% and 62.5% from the manual harvesting costs and traditional plough respectively.

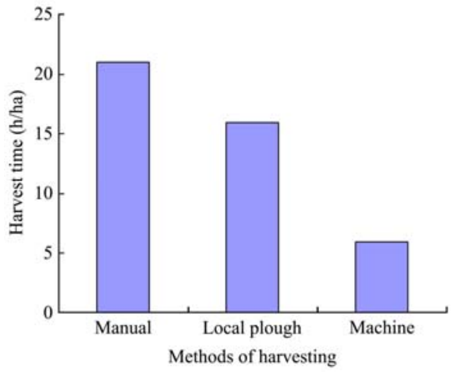



Figure 9 Harvest time (h ha$^{-1}$) for manual, traditional plough and self propelled machine

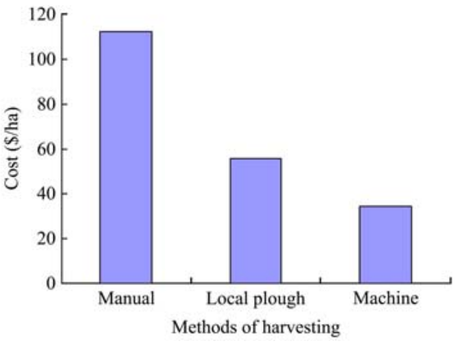



Figure 10 Harvest cost ($ ha$^{-1}$) for manual, traditional plough and self-propelled machine

## 4 Conclusion

The obtained results can be summarized as follows:

1) The percentage of damaged tubers increased by accelerating the speed from 1.5-2.5 km h$^{-1}$, but the damaged percentage decreased with increasing the digging depth.

2) Results showed that the highest value of field capacity was at digging depth of 16 cm and forward speed of 2.5 km h$^{-1}$.

3) Results showed that the highest value of harvesting efficiency was found at the digging depth of 24 cm and forward speed 2.5 km h$^{-1}$. The harvester efficiency decreased by accelerating the speed from 1.5 to 2.5 km h$^{-1}$ at different digging depths of 16, 20, and 24 cm.

4) Results showed that the lowest value of the consumed energy was found at the digging depth of 16 cm and forward speed of 1.5 km h$^{-1}$. The consumed energy decreased in the speed range 1.5 to 2.0 km h$^{-1}$, Energy increased with increasing digging depth.

5) It was found that the highest value of the missing tubers percentages was at the digging depth of 16 cm and forward speed 1.5 km h$^{-1}$. By increasing the digging depth the missing tuber decreased.

6) Results showed that the minimum cost was found at digging depth of 16 cm and forward speed 2 km h$^{-1}$.

7) Results showed that the lowest value of harvesting time was by using of the self propelled machine. Where the harvesting time decreased to 25%, 30% comparing with manual harvesting time and traditional plough respectively.

8) The harvesting cost value of the self-propelled machine was 34$ ha$^{-1}$, so, it was decreased by 31.25% and 62.5% comparing with manual harvesting costs and traditional plough, respectively.

## References

Awady, M. N. 1978. Engineering of tractors and agricultural machinery. Text Book, Col. Ag. Ain-shams Univ., 5th. 161–164. (In Arabic, updating 1998)

Bentini M., C. Caprara and R. Martelli. 2006. Harvesting damage to potato tubers by analysis of impacts recorded with an instrumented sphere. *Biosystems Engineering*, 94(1): 75–85.

FAO. 2010. Food and Agriculture Organization of the United Nations (FAO). Egypt-Agr. Census 1999/2000: 54–55.

Field, H. L. and J. B. Solie 2007. Introduction to Agricultural Engineering Technology. A Problem Solving Approach. 3th ed. Springer Science+Business Media, LLC 233 Spring Street, New York, NY 10013, USA

Horton D. and R. L. Sawyer. 1985. The potato as a world food crop, with special reference to developing areas. In: *Potato Physiology*, ed. P. H. Li, ch. 1, 1–34. Orlando, Florieda, Academic Press Inc.

Mathew, R. and G. M. Hyde. 1997. Potato impact damage thresholds. *Transactions of the ASAE*, 40(3): 705–709.

Nasr ,G. E. 1992. Labor requirements and production cost for sugar beet harvesting using different type of sugar beet harvester. *Misr Journal Agricultural Engineering*, 9(2): 191–207.

Storey, R. M. J. and H. V. Davies. 1992. Tuber quality. In.*The Potato Crop*., ed. P. Harris, ch. 12, 507–569. London: Chapman and Hall.

Stout, B. A., and B. Cheze. 1999. *Handbook of Agricultural Engineering. Volume III. Plant Production Engineering*. 8th ed. St. Joseph: ASAE.