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# DEVELOPMENT AND PERFORMANCE EVALUATION OF A LOCAL HARVESTING MACHINE FOR ONION CROP

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## Abstract

Field experiments were carried to evaluate a single-row developed machine at El-qureen city, Sharkia Governorate, Egypt. A local peanut harvesting machine has been developed to perform total mechanical harvesting of onion. The planted onion crop variety was Beheri (red). The performance of the developed harvesting machine was conducted under the following parameters: different forward speeds of 1.7, 2.4, 3.1 and 3.8 km.h$^{-1}$ and soil moisture contents (d.b.) of 9.4, 12.7, 15.8 and 18.8 %. The performance of the developed machine was evaluated taking into consideration field capacity and efficiency, total harvesting losses, lifting efficiency, machine productivity, required power, specific energy, operating and total costs. The experimental results revealed to operate the developed machine with high field capacity, efficiency and low specific energy and total cost, the proper forward speed and soil moisture content are 3.1km.h$^{-1}$ and 15.8% (d.b.) at constant digging depth, pulling chain speed and penetration angle were 10.0 cm, 66.13 m.min$^{-1}$ and 10°, respectively.

***Keywords*:** Onion, mechanical harvesting, local machine, lifting, chain speed.

## Introduction

Onion considers one of the most important vegetables and root crops in Egypt. The total onion cultivated area in Egypt is about 0.162 million feddan with yearly produced about 2.379 million Mg and an average 14.68 Mg.fed$^{-1}$ according to FAO (2017). Onion is a perennial plant and contains two main parts the bulb and the vegetative growth (tube leaves). Khura *et al.* (2010) studied some engineering properties of onion crop related to design of harvesting machine. About 94% of bulbs distributions underneath the ground surface were within 6 cm depth. The plant length ranged from 11.0 to 32.0 cm, with average 17.76 cm, at row-to-row spacing of 14 cm. The values of equatorial and polar diameter for small, medium and large onion were 34.5-33.8, 49.82-41.41 and 64.68-53.20 mm, respectively. The average bulb weights were 21, 52 and 112 g for three previous sizes and the bulk densities were 0.18, 0.26 and 0.29 Mg.m$^{-3}$ in the same order. Harvesting of onion from the field is an important operation in the cultivation of onion crop, which has to be carried out during crop maturity and at optimum time to minimize field losses; Hole *et al.* (2000) reported that structure and composition of onion crop skins are the most important factors affecting skin quality. Higher moisture content of skins is stronger in mechanical properties values and feebler in stiffness. Where onion crop is grown below the surface of the ground, therefore bulbs require specially designed machines to dig and lift them from the soil, those operations are the most labor intensive operations in onion harvesting. Harvesting process of onion crop is still carried out manually with a long time consumed, more losses and costs. Ashwini *et al.* (2014) concluded that onion harvesting operation is rigorous and requires massive amount of manpower and time. Main reason of low productivity and high costs is deficient power and machinery equipment availability on the farm and low farm mechanization. Omar *et al.* (2018) developed and evaluated the performance of an onion harvester under four digging depths (4, 6, 8 and 10 cm) and four different forward speeds (0.720, 0.837, 0.947 and 1.125 km.h$^{-1}$) at constant 22% soil moisture content. The results showed that, the highest field efficiency and lifting efficiency were 73.9 and 99.2%, respectively at 0.720 km.h$^{-1}$ forward speed and 4 cm digging depth, the lowest total losses, power and energy consumed were 1.9%, 10.11 kW, 59.5 kW.h.fed$^{-1}$, respectively, at the same previous conditions, the total cost was 674.33 L.E.fed$^{-1}$ at the same previous forward speed and 10 cm digging depth, compared with 2400 LE.fed$^{-1}$ for manual method. Mahesh (2014) developed harvesting digger for onion bulbs, results indicated that at forward speed of 4km.h$^{-1}$ achieved harvesting operation with minimum losses and field capacity of 1.10 fed.h$^{-1}$. Digging depth of 7.62 cm was proper with almost without damage. Mean digger efficiency, lifting efficiency and damage percentage were 89.8, 94.9 and 5.1%, respectively. Khurana *et al.* (2012) tested a prototype harvester for digging root crops instance onion, garlic and carrot. The field capacity values were 0.48, 0.55 and 0.60 fed.h$^{-1}$ at forward speeds of 2.1, 2.5 and 2.7 km.h$^{-1}$ for the same order crops, respectively. A percentage of exposed crops and damage were (99.0 , 1.0), (98.6 , 1.1) and (96.3 , 2.8) % for the same crops, respectively. Saving in labor and cost of harvesting operation compared to manual method about (69.0 , 54.74), (61.4 , 45.91) and (59.2 , 47.12)% for the same crops, respectively. Therefore, mechanical harvesting offers the possible solution for reducing labor, time and total cost of onion harvesting. So the main goal of this work was to develop peanut harvesting machine to be suitable for total mechanical harvesting of onion crop. Therefore, the objectives of this research are:

Optimize some operating limitations (forward speed and soil moisture content) affecting the performance of the developed machine, evaluate the developed machine from the economic perspective with permitting using the machine once more for peanut in summer season to maximize the utilization efficiency all over the year.

## Material and Methods

Field experiments were carried out using the developed harvesting machine during 2018-2019 season in an area of 1.5 feddans (the experimental soil was classified as sandy soil with 92.4 % sandy percent) at El-qureen city, Sharkia Governorate. Onion crop variety was Beheri (red) and transplanted manually to evaluate the performance of a harvesting machine suitable for total mechanical harvesting of onion.

## Material

### Crop

Onion (*Allium Cepa* L.) is one of the Alliaceae family, which considered a perennial plant, and contains two main parts the bulbs and the vegetative growth (tube leaves). Some physical properties of onion plant Beheri (red) variety summarized on Table (1). Row spacing was 0.9 m, the distance between plants in length of the row 0.1 m, the bed width was 0.3 m and the number of onions plant breadth the row on the bed was 3 onions. The bulbs grow under the soil and takes away under surface up to 4-9 cm depth.

**Table 1 :** Some physical properties of onion (Beheri red).

| **Physical characteristics** | Bulb Length, cm | Bulb diameter, cm | foliage cluster diameter, cm | foliage height, cm | Bulb mass, gm | foliage mass, gm |
|---|---|---|---|---|---|---|
| **Average value** | 4.9 | 5.9 | 2.8 | 22.7 | 125.3 | 62.6 |

### The machine before development

It performs direct harvesting of peanut crop, and was fabricated by Nour *et al.* (2016). It trailer behind the tractor by two point hitches of a tractor and takes movement by PTO, the technical specifications were overall (length, width, height and mass) of 3.7, 1.0, 1.0 m and 0.45 Mg, consecutively. It was consisted mainly of digging and dislocation unit, separating unit, cleaning unit, conveying unit, transmission system, main frame and land wheels as shown in Fig. 1.

**Digging and dislocation unit :** It consist of straight-shaped digging blade (60cm width*17cm length*1.2cm thickness) with tilt angle 10$^{\circ}$ and double chains with fingernails, which catch the tops of the loosened plants then lift them with its movement up to the end of the machine. The each chain has length 474 cm and take the power from main shaft (sprocket fixed on the main shaft) which operated by the gear box through pulleys and belts.

**Separating unit :** The unit consists of a set of rubber fingered belts operated by pulleys and belts from main shaft to achieve stripping operation of pods without any damage.

**Cleaning unit :** The cleaning unit was a sieve, which used to clean and separate peanut pods from the soil then transfers them to the conveyor.

**Fig. 1:** The machine before development.

**Conveying unit :** The rubber elevator was used for lifting pods from the sieve to the collecting bag.

**Transmission system :** The machine has gear box powered from tractor PTO by universal joint, the power transmitted from gear box to the other moving parts by means of pulleys and belts with different speeds ratios.

**Main frame :** The all previous units and their parts were fixed on the frame. The main frame was made of iron steel U-section 80×40 mm and 6 mm thickness of dimensions 210 cm length, 60 cm width, and 50 cm height. It was carried by two tire ground wheels of 50 cm diameter.

### The developed machine

It was modified to achieve harvesting of onion crop at local workshop in Faquas, Sharkia Governorate, Egypt. The modifications were exclusion (the sieve, four rubber fingered belts and the conveying unit), adding (cutting discs) and modification (the shear, harvester height, the fingered belts and sizes of some pulleys and belts), with capability of simplicity return the machine to the original case at using it for peanut. It trailer behind the tractor with digging width of 0.6 m, overall (length, width, height) of 3.1, 1.0, 1.3 m, respectively and total mass of 0.36 Mg. The developed machine has main five components of digging and dislocation unit, cleaning unit, separating bulbs unit, transmission system and mainframe as shown in Figs. (2 and 3).

**Fig. 2 :** The developed machine.

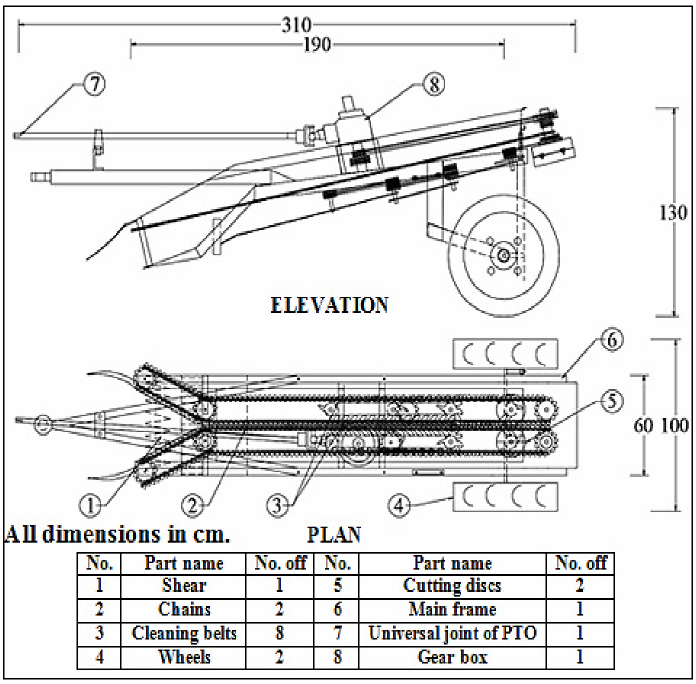


**Fig. 3 :** The views of the developed machine.

**Digging and dislocation unit :** All parts as the same before development but the apertures of shear were increased inward to decrease the traction soil forcing of the shear and covered the front of chains as shown in Fig.4.

**Cleaning unit :** The unit contains a set of stationary rubber fingered belts fixed on pulleys down the pulling chains to clean bulbs from any adhesion soil during enters into rubber fingers without any bulbs bruise.

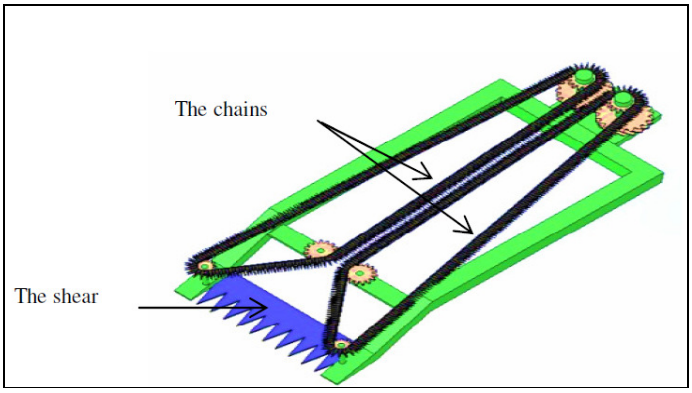


**Fig. 4 :** Digging and dislocation unit.

**Separating bulbs unit :** Separating unit consists of two serrated cutting discs with 18 cm diameter and clearance between discs 4.76 mm, to achieve the stripping operation of bulbs without any damage, where the crown zone enters into discs which move in the opposite direction of plant movement in order to work on separation of the bulbs from the plant. Then the bulbs fall in the collection bag in rear of the machine. The cutting discs are operated by the main chain's shaft through pulleys and belts.

**Transmission system :** As the same before development with some changes, where the movement transmitted from tractor PTO to gearbox then the main chain's shaft, after that to chains through the fixed sprocket on the main shaft and to cutting discs through pulleys and belts.

**Main frame** : The same specifications before modifying with adding two bar from iron steel U-section 80×40 mm, 6 mm thickness and 300 mm height on axis of the wheels to rectify harvester height and slope, it has a controlling hand lever to adjust tilt angle with help of bolts and nuts.

**Power supply**

The tractor model was Kubota D902, its Power at rate speed 17.2 kW (23.0 hP) with 540 PTO rpm and the tractor mass was 0.70 Mg.

**Methods**

A field experiments were carried out in abo nour farm, El-qureen city, Sharkia Governorate, Egypt, to evaluate the developed onion harvesting machine, which performs complete mechanical harvesting, following the next stages: Dislocation of the plants in conditions of low humidity, pulling the plants out of the soil, removing the soil and eliminating impurities, cutting the bulbs from the plant and collects bulbs in bag. From pre-experiments and onion physical properties, the digging depth was adjusted to be 10.0 cm, pulling chain speed of 66.13 $m.min^{-1}$ and penetration angle $10^{\circ}$.

**The performance of the developed machine was experimentally measured under the following parameters:**

1- Forward speeds of 1.7, 2.4, 3.1 and 3.8 $km.h^{-1}$.

2- Soil moisture contents (d.b.) of 9.4, 12.7, 15.8 and 18.8 %.

**Measurements and determinations:**

Evaluation the performance of the developed machine was based on the following indicators:

**Field capacity**:

The theoretical field capacity was determined from the following formula (Kepner *et al*., 1978):

$$TFC = \frac{F_S \times W_m}{4.2}$$

Where:

TFC = Theoretical field capacity, [$fed.h^{-1}$].

$F_s$ = Forward speed, [$km.h^{-1}$].

$W_m$ = Working width of the machine, [m].

The effective field capacity was determined from the next equation:

$$EFC = \frac{60}{Tu + Ti}$$

Where:

*EFC* = Effective field capacity, [$fed.h^{-1}$].

*Tu* = Utilized time per feddan, [min.].

*Ti* = Summation of lost time per feddan, [min.].

**Field efficiency:**

It is calculated as follows: $\eta_f = \frac{EFC}{TFC} \times 100$

Where:

$\eta_f$ = The field efficiency, [%].

EFC = Effective field capacity, [$fed.h^{-1}$].

TFC = Theoretical field capacity, [$fed.h^{-1}$].

**Total yield:**

The yield of the harvested bulbs was measured and calculated per feddan by the following equation (Taieb, 1997):

$$Y = \frac{M \times 4200}{A \times 1000}$$

Where:

Y = Total bulbs yield, [$Mg.fed^{-1}$].

M = Mass of bulbs, [kg].

A = Harvested area, [m²].

**Machine productivity**:

The yield productivity was calculated according the following formula:

Where: $P = Ub \times EFC$

P = Machine productivity, [$Mg.h^{-1}$].

$U_B$ = Undamaged bulbs, [$Mg.fed^{-1}$].

EFC = Effective field capacity, [$fed.h^{-1}$].

**Total harvesting losses**:

Total onion bulbs losses percentage was calculated by the next equation:

$$Tloss = \frac{Ul + Db}{Y} \times 100$$

Where:

$T_{LOSS}$= Total losses, [%].

$U_L$= Mass of unlifted bulbs, [$Mg.fed^{-1}$].

$D_B$ = Mass of damaged bulbs, [$Mg.fed^{-1}$].

Y = Total bulbs yield, [$Mg.fed^{-1}$].

**Lifting efficiency**

It was calculated according to the following equation:

$$\eta l = \frac{Lb}{Y} \times 100$$

Where:

$\eta_L$= Lifting efficiency, [%].

$L_B$ = Mass of lifted bulbs, [$Mg.fed^{-1}$].

Y = Total bulbs yield, [$Mg.fed^{-1}$].

**Required power:**

It was calculated by using the next formula (Hunt, 1983):

$$EP = f.c.(1/3600)\rho_f \times l.c.v. \times 427 \times \eta_{thb} \times \eta_m \times \frac{1}{75} \times \frac{1}{1.36}$$

Where:

*EP = Required* power, [kW].

*f.c.* = Rate of fuel consumption [$l.h^{-1}$].

$\rho_f$ = Density of fuel, [$kg.l^{-1}$] (for diesel engines = 0.85 $kg.l^{-1}$)

*l.c.v.* = Average calorific value of diesel fuel, (11000 $kcal.kg^{-1}$)

$\eta_{thb}$ = Thermal efficiency of the engine = 30%.

427 = Thermo – mechanical equivalent, [$kg.m.kcal^{-1}$].

$\eta_m$ = Mechanical efficiency of the engine = 83%.

**Specific energy**:

It calculated by the following equation:

$$SE = \frac{EP}{EFC}$$

Where:

SE = Specific energy requirements, [$kW.h.fed^{-1}$].

EP = Required power, [kW].

*EFC* = Effective field capacity, [$fed.h^{-1}$].

**Cost analysis**:

The cost of mechanized process was based on the initial cost of machine, interest on capital, cost of fuel and oil consumed, cost of maintenance, and wage of operator according to the following formula (Awady, 1978):

$$C = \frac{p}{h}\left(\frac{1}{a} + \frac{i}{2} + t + r\right) + (1.2\,W \times s \times f\,) + \frac{m}{144}$$

Where:

C= Hourly cost, [$LE.h^{-1}$].

P=price of machine, [LE].

h= Yearly working hours, [$h.year^{-1}$].

a=Life expectancy of the machine, [year].

i= Annual Interest rate, [%].

t=Annual Taxes, over heads rate, [%].

r = Annual Repairs and maintenance rate, [%].

f=fuel price, [LE].

1.2= A factor including estimation of the oil and fuel consumption.

W=Engine power, [hp].

S=Specific fuel consumption, [$l.hp^{-1}. h^{-1}$].

m= Monthly average wage, [LE].

144=Reasonable estimation of monthly working hours.

**Operating cost:**

Operational cost can be determined using the following formula:

$$Cop. = \frac{C}{EFC}$$

Where:

$C_{op.}$= Operating cost, [$LE.fed^{-1}$].

C = Hourly cost, [$LE.h^{-1}$].

EFC = Effective field capacity of the machine [$fed.h^{-1}$].

**Total costs:**

It was estimated using the following equation (Awady *et al;* 1982):

Total cost = operating cost +Total losses cost [LE .$fed^{-1}$]

Where, the price of kilogram for onion was taken to be 2.00 LE.

## Results and Discussion

The obtained results will be discussed under the following items:

**Filed capacity and efficiency**

Representative values of both filed capacity and efficiency versus with forward speeds at different soil moisture contents are given in Figs. (5 and 6). Increasing forward speed from 1.7 to 3.8 $km.h^{-1}$ measured at different soil moisture contents of about 9.4, 12.7, 15.8 and 18.8%, followed with an increase in filed capacity from (0.304 to 0.579), (0.316 to 0.612), (0.329 to 0.638) and (0.302 to 0.575) $fed.h^{-1}$, and a decreased in field efficiency from (83.38 to 71.19), (86.86 to 75.14), (90.37 to 78.35) and (83.02 to 70.69) %, respectively under the mentioned M.C. The filed capacity increased by increasing forward speed due to the decrease in time achieving of harvesting operation. While, the field efficiency decreased due to the excessive load of plants on pulling chains and machine devices, cause more stops and failure. Higher values of moisture content more than 15.8% lead to decrease filed capacity and efficiency because increasing in the slippage. Lower values of moisture content less than the optimum value 15.8% tend to decrease filed capacity and efficiency because of increasing in soil resistance.

**Machine productivity and total harvesting losses**

Values of both machine productivity and total harvesting losses versus with forward speed at different soil moisture contents are given in Figs. (7 and 8). Obtained results showed that increase of forward speed from 1.7 to 3.8 km.h$^{-1}$ measured at the same different soil moisture contents, was followed with an increase in the machine productivity from (3.603 to 6.791), (3.761 to 7.219), (3.919 to 7.548) and (3.571 to 6.728) Mg.h$^{-1}$ and also increased total harvesting losses from (1.283 to 2.299), (0.858 to 1.725), (0.783 to 1.482) and (1.745 to 2.508)%, respectively. Machine productivity was increased by increasing forward speed due to the increase in values of field capacity. And also, total harvesting losses increased due to increase un-lifted bulbs because of piling up of soil in front of the shear, and due to the increase in damaged bulbs because of the excessive load of plants on the machine devices.

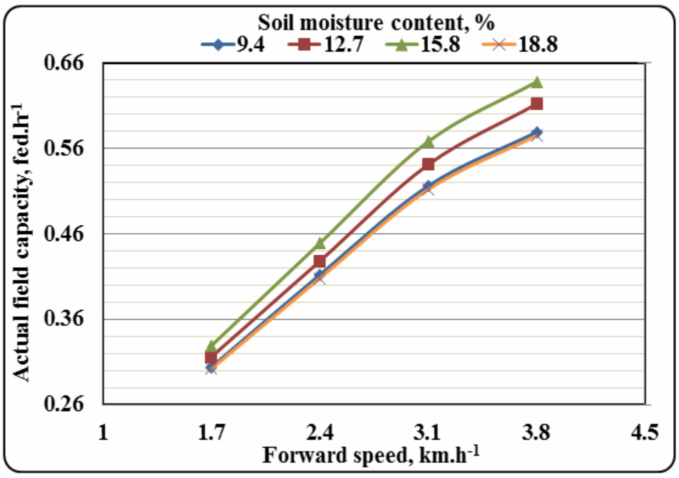


**Fig. 5:** Effect of forward speed on filed capacity at different soil moisture content.

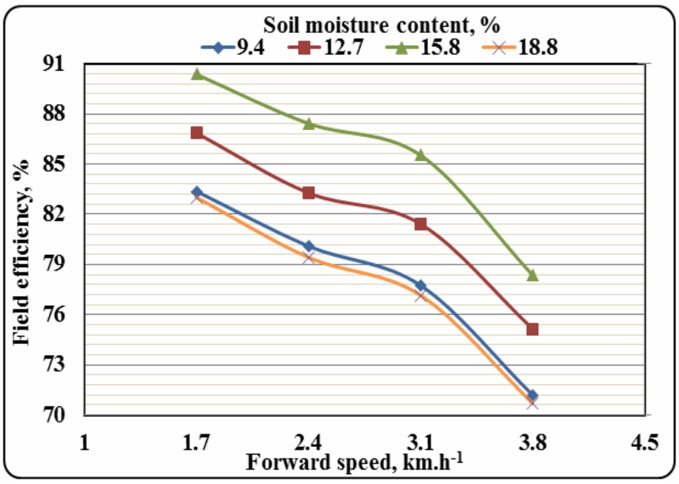


**Fig. 6:** Effect of forward speed on field efficiency at different soil moisture content.

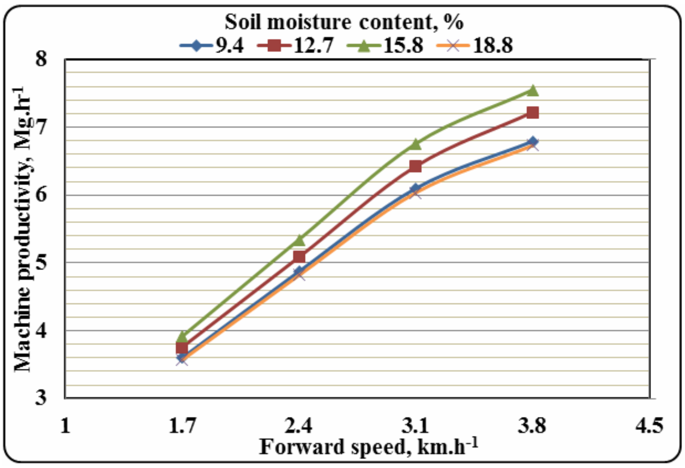


**Fig. 7 :** Effect of forward speed on machine productivity at different soil moisture content.

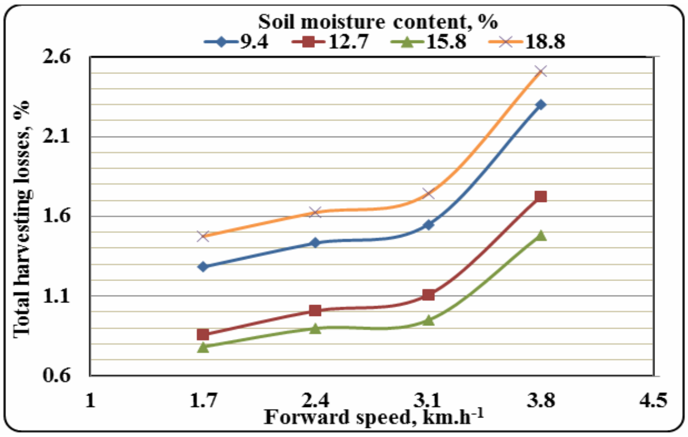


**Fig. 8 :** Effect of forward speed on total harvesting losses at different soil moisture content.

The values of machine productivity were increased with increasing of moisture contents up to15.8% due to ease penetration of the soil, any further increase after that causes decreasing of machine productivity due to great increase in the slippage. Total harvesting losses were decreased with increasing of moisture contents up to15.8% due to decrease the digging losses because of decreasing both the adhesion of soil with bulbs and the cohesion between the soil particles, any further increase in moisture content after previous value causes increasing of total losses due to great increase in adhesion of soil with shear and bulbs.

**Required power, specific energy and total costs**

Representative values of required power, specific energy and total cost versus with forward speed at different soil moisture contents are given in Figs. (9 and 10). The increase of forward speed from 1.7 to 3.8 km.h$^{-1}$ measured at different soil moisture contents of about 9.4, 12.7, 15.8 and 18.8%, was followed with an increase in required power from (10.00 to 12.22), (8.62 to 10.76), (8.35 to 10.24) and (9.73 to 11.90) kW, while a decrease in specific energy from (32.89 to 21.11), (27.27 to 17.58), (25.37 to 16.05) and (32.21 to 20.69) kW.h.fed$^{-1}$, and also increasing forward speed up to 3.1 km.h$^{-1}$ measured at the same previous soil moisture contents decreased total costs from (555.50 to 517.81), (444.10 to 405.08), (416.69 to 360.46) and (603.14 to 564.95) LE.fed$^{-1}$, respectively. The further increase in forward speed more than 3.1 up to 3.8 km.h$^{-1}$ caused an increase in total cost from (517.81 to 681.95), (405.08 to 536.94), (360.46 to 473.93) and (564.95 to 732.85) LE.fed$^{-1}$ under the mentioned M.C, respectively. The power increased by increasing forward speed due to the increase in fuel consumption. While, the energy decreased with forward speed due to decrease the field capacity more than increasing of required power, and also total cost decreased with forward speed up to 3.1km.h$^{-1}$ and after that increased due to increase total harvesting losses more than decreasing in operating cost.

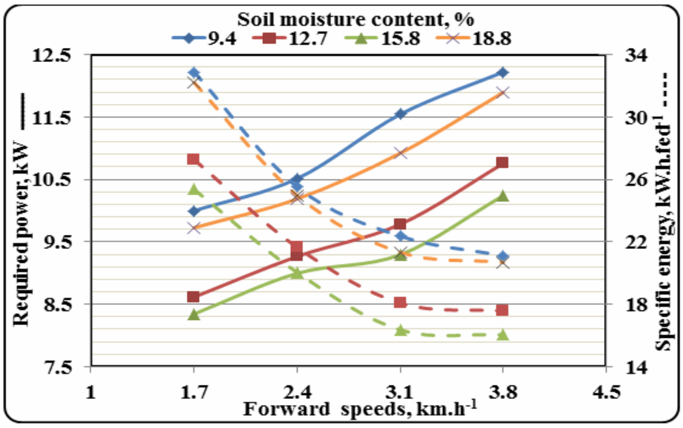


**Fig. 9 :** Effect of forward speed on required power and specific energy at different soil moisture content.

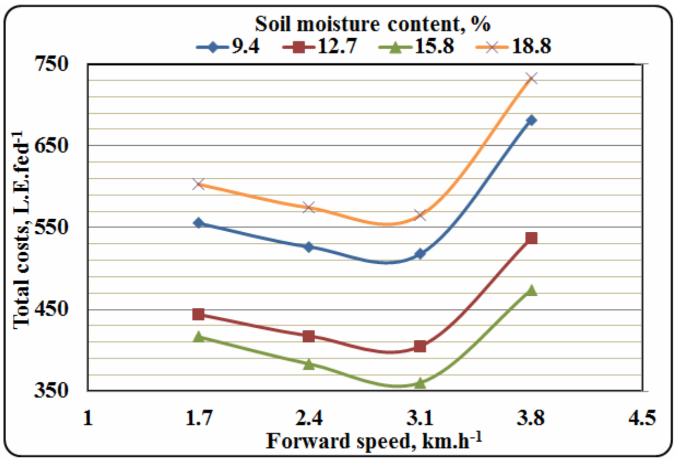


**Fig. 10:** Effect of forward speed on total costs at different soil moisture content.

Required power and specific energy were decreased by increasing soil moisture contents up to 15.8% because decreasing in soil penetration resistance consequently decreasing fuel consumption, any further increase after the mentioned value of M.C lead to increase both of the power and energy due to increase the slippage. Total costs decreased by increasing soil moisture content up to 15.8%, and after that the total cost increased because of decreasing in filed capacity and increasing total harvesting losses.

## Conclusion

The aim of this research was develop a single row peanut harvesting machine to achieve total mechanical harvesting of onion crop, from obtained results, the conclusions as following:

- The maximum values of filed capacity and machine productivity were 0.638 fed.h$^{-1}$ and 7.548 Mg.h$^{-1}$, respectively, at 3.8 km.h$^{-1}$ forward speed and soil moisture content (d.b.) of 15.8 %.
- The minimum value of specific energy was 16.05 kW.h.fed$^{-1}$ at the above previous conditions.
- The highest values of field and lifting efficiency were 90.37 and 99.54 %, respectively, at 1.7 km.h$^{-1}$ forward speed and soil moisture content (d.b.) of 15.8 %.
- The least values of total losses and required power were 0.783 % and 8.35 kW at the same previous conditions.
- The lowest value of total costs was 360.46 LE.fed$^{-1}$ at 3.1 km.h$^{-1}$ forward speed and the same preceding soil moisture content.

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