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Development of Self-Propelled Onion Digger for Small Farmers

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A B S T R A C T

Onion harvesting machinery like all other farm equipment has passed through various stages of development. Our research work had focused on ease of handling and harvesting of onion in less time for small land holders at low cost by considering different factors as power requirement, cost of equipment, ease of operation and time of operation. Self-propelled onion digger required only one person to operate. Our Design objective is to come up with a self-propelled onion digger that was easily transportable, durable, easy to operate and maintainable for small farmer. By conventional method of harvesting one ha of land requires 96 man-hours, which accounts for Rs.4800/ha. Thus, keeping this in view to reduce labor cost, we developed the machine of cost Rs.15,584 which can harvest one ha of land in 8 hours. The maximum digging efficiency of the self-propelled onion digger is 97 % and minimum plant damage percentage is 1.67 %.The savings in cost and time by using self-propelled onion digger compared with traditional method of harvesting is 81.9% and 91.3%.

Keywords

Onion, Digger, Digging efficiency and bulb damage

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Introduction

India is the world's second largest producer of onion (*Allium cepa L.*) after China and it is one of the most important bulbs as well as cash vegetable crop belongs to family Alliaceous. In India, onion is being grown in an area of 5.30 million hectare which gives total production of 88.48 million tons with productivity 16.70 tons per hectare. In India, Onion crop is grown in about 1.20-million-hectare area with an annual production of 19.40 million tons with productivity 16.12 tons per hectare (Anonymous 2017). Mechanization of onion harvesting is needed as traditionally; the well-matured bulbs are harvested by hand shovel (khurpa) which requires 21.4% of total expenditure of onion cultivation. Also, it is necessary to complete the harvesting operation of onion within specified time limits for reduced harvest losses and higher storage life. For onion growers in India an economical partial mechanized onion harvesting would be a mechanical harvester which can dig the onion, help detaching soil and mixture, separating soil mass and finally windrowing the harvested crop which can be picked up manually. Onion was planted in flatbed or broad-based furrow (BBF) with a spacing of 15×10 cm for both. Onion were generally harvesting by hand due to the high damages caused by the mechanical harvesting. Even though due to the lack of laborers in agricultural work, mechanical harvester for onion is need of the hour. Manual harvesting of onions is a tedious, time consuming, labor intensive and costly operation so mechanization of harvesting is essentially needed. Mechanization of onion harvesting needs as traditionally, the well-matured bulbs are harvested by hand shovel (khurpa) which requires 21.4 per cent of total expenditure of onion cultivation (Ashwini *et al.,* 2014). Lorenzo and Abenavoli *et al.,* (2004) reported that manual harvesting alone, accounts for more than 50% of total production costs. Mechanized harvesting (by means of onion pullers, windrowers, harvesters and, possibly, stem cutters), instead, results in work productivity 5 to 6 times higher than that of manual operations. The aim of the study is to develop and evaluate a prototype onion digger for small farmers.

Jafar Massah *et al.,* (2012) found at vehicle speed of 1.8 km/h and the blade angle of 20 degree. The percentage of the damaged bulbs caused by the harvester was less than the manual method. Mahesh C.S (2014) developed and evaluated digger performance at the experimental site. The digger was operated with a speed of 4 km/h in first high gear with minimum losses at a field capacity of 0.46 ha/h. Depth control wheels were effective to control the depth of cut by blade. The average operational depth of 7.62 cm of the developed digger was suitable with practically no damage to the onion bulbs. Lift percentage, mean digger efficiency and damage percentage were 94.9, 89.8 and 5.1%, respectively. Budhale *et al.,* (2019) reported that the depth of onion harvesting was depending upon depth of onion in soil bed. As per considering average biometric properties of onion the depth of harvesting is in range of 7-10 cm. So, for harvesting without damage to onion crop the depth of operation was selected as 10 cm. Omar *et al.,* (2018) indicated that, the maximum field capacity was 0.180 fed/h at speed of 1.125km/h and the maximum field efficiency was 73.9 % at speed of 0.720km/h, it was recorded at depth of 4cm, compared with manual method which recorded the field capacity and field efficiency were 0.125 fed/h and 84.26%, respectively. It was recommended to operate the developed harvester for harvesting onion crop at a depth harvesting of 10 cm and a forward speed of 0.720 km/h. Nisha and Shridar (2018) evaluated the performance of power tiller operated small onion harvester was field tested for harvesting CO (On) 5 varieties and they found that the field capacity was 0.08 ha h^{-1}. The saving in cost and time were 59.2 and 93.75 % respectively as compared to the conventional method of manual harvesting. The harvesting, conveying and soil separation efficiency of the developed harvester is 97.4, 86.9 and 84 %.

Materials and Methods

Physical properties of onion

The parameters influencing the digging of onion were identified and determined. We have measured the maximum depth of onion in the soil, onion stem height and width of onion coverage in the soil for *Allium cepa* variety. From these physical properties it is desired to design a digger blade which should not damage the onions during digging and should be able to dig and lift the onion from the soil.

Comparison with traditional method

In India most of the onion is harvested manually. Manual harvesting of onion is done by use of Khurpa or spade which is a labor intensive and time-consuming operation. This traditional method of digging is compared with self-propelled onion digger in terms of cost of digging and field capacity.

Development of prototype onion digger

A prototype onion digger was developed with Power unit, Power transmission unit, Blade, Ground wheel, handle and depth control wheel. The overall dimension of the self-propelled onion digger is 1000 mm × 870 mm × 1100 mm. The main frame of the digger is fabricated to supports the components of onion digger such as speed reduction unit, pulley, power unit, wheels. Power required to run the onion digger was 4 hp with 3600 rated rpm and it is fixed on motor bed at a height of 40mm (Fig. 1).

Pulley

A compound belt drive, is used when power is transmitted from one shaft to another through number of pulleys. Speed reduction Pulleys are made up of cast iron and are connected by means of V belts.

$$\boldsymbol{\pi D_1 N_1 = \pi D_2 N_2} \qquad \text{..... (1)}$$

Where
N_1 = Speed of driven pulley
N_2 = Speed of driver pulley
D_1 = Driven pulley diameter
D_2 = Driver pulley diameter

Reduction of 2800 rpm to 25 rpm is needed,
Pulley, P1 = 3 inch (7.5 cm)
Pulley, P2 = 18 inch (45 cm)
Pulley, P3 = 3 inch (7.5 cm)
Pulley, P_4 = 12 inch (28 cm)
Operation of walking speed = 2.3 $km.h^{-1}$
Diameter of wheel = 50 m

1 st Reduction $D_1 N_1 = \pi D_2 N_2$

$$N_2 = \frac{D1\ N1}{D2} = \frac{7.5 \times 2800}{45} = 466.6 \text{ rpm}$$

2 st Reduction

$$N_4 = \frac{D3\ N3}{D4} = \frac{7.5 \times 466.6}{4528} = 124 \text{ rpm}$$

Chain and sprocket

Chain drive is a way of transmitting mechanical power from one place to another. A power transmission system takes place within a chain and two sprockets. The chain meshes with the sprockets, transmitting rotary motion between two sprockets (Fig. 2).

3^{rd} reduction

$$T_1 N_5 = T_2 N_6 \qquad \text{..... (2)}$$

$$N6 = \frac{T1\ N5}{T2} = \frac{13 \times 124}{65} = 25 \text{ rpm}$$

With the help of pulley and chain sprocket 2800 rpm is reduced to 25 rpm.

Length of chain

$$\mathbf{L} = \frac{\pi}{2}(d_1+d_2)+2x+\frac{(d_1-d_2)^2}{4x} \qquad \text{..... (3)}$$

Where,
L is length of chain
d is diameter of sprocket
x is center to center distance between shaft
Number of Teeth, T_1 = 13, T_2 = 65

Diameter of sprocket d_1 = 5 cm, d_2 = 25 cm
Center to center distance, x = 20 cm

$$L = \frac{3.14}{2}(5 + 25) + 2 \times 20 + \frac{(5-25)^2}{4 \times 25}$$
L = 92.1 cm

V Belt: V- Type of belt used for connecting the pulleys, where a same amount of power is to be transmitted, from one pulley to another pulley. The pulley is mounted on the shaft that are parallel to each other (Fig.1).

Length of belt for 1st reduction

Diameterofpulleyd_1= 7.5cm, d_2 = 45 cm and Centre to centre distance x = 35 cm

$$L = \frac{\pi}{2}(d_1 + d_2) + 2x + \frac{(d_1-d_2)^2}{4x} \quad \ldots.. (4)$$
L = (1.57 x52.5) + 40 + 10.038
L = 162.46 cm (or) 65 inchso 65 B type pulley was chosen.

Length of belt for 2nd reduction

Diameter of pulleyd_1= 7.5 cm, d_2 = 45 cm and Centre to centre distance x = 32 cm therefore L = 123 cm, so V belt of 49 B type pulley was chosen.

Power transmission unit

A 4 hp air cooled petrol engine is fitted on the main frame at an appropriate place. Provision is made at the base point to move the engine to create a belt tension with the help of V pulley fitted to the engine and compound V belts. It also provided the tension mechanism to create belt tension or slack at necessary time.

Digging blade

Mild steel Blade is used to dig the onions and height, width and thickness of the blade is 170,75and 6mm respectively. The cutting edge of the blade is provided with an angle of 45° for 5o mm height (Fig. 3).

Handle

The handle is provided at the rear side of the digger to hold and steers the machine. The handles are made of 250mm mild steel hallow circular pipe. The length of the handle is 900 mm and 550mm twisted is given at the purpose of connection. The length of the handle crossbar is 175mm which is provided between two handles for providing stability (Fig. 2).

Ground wheel and shaft

A light weight ground wheel is attached to the digger for the traction of implement. The ground wheel is 600 mm in diameter with 100 mm width and it is made of 12 mm mild steel round rod, the clearance between the ground wheel were adjustable according to the ridge spacing. The ground wheel has a shaft with a diameter of 25 mm with a length of 900 mm which connects the main frame and the two wheels (Fig. 4).

Depth control wheel

The depth control wheel with a diameter of 200 mm and the width of 20 mm is fixed at the rear side of digging tool bar. The depth can be varied according to the digging depth. The square tube is attached to the depth wheel which consists of number of holes which is used to change the height of the depth wheel (Fig. 2).

Performance evaluation of self-propelled onion digger

The harvesting efficiency of the onion digger was studied using a portable onion digger. The parameters recorded while evaluating the performance of the digger were operational speed of digger, depth of operation, Weight of onion lifted, weight of onion damaged and Weight of onion left undigged. Onions were transplanted on 60 cm wide bed with row to row spacing of 15 cm and plant to plant spacing of 7.5 cm (Fig. 5). The onion was harvested at the age of 107 days after sowing.

Field capacity

The field capacity and field efficiency of the unit was found by operating the unit in an area of 50 cent. The total time taken to cover the area, time lost for running at head lands and other time losses were recorded for the calculation of field capacity.

$$\text{Theoretical field capacity} = W * S \quad \text{..... (5)}$$

Where W - Width of operation
S - Speed of operation

Actual field capacity is the actual area covered by the self-propelled onion digger in a particular time.

Digging efficiency

The digger efficiency was calculated using the equation given below (Ibrahim *et al.*, 2008).

$$\eta = (Wr/ (Wr+Ws)) \times 100 \quad \text{..... (6)}$$

Where,

η - harvesting efficiency, per cent
Wr - weight of onion collected from harvesting the clumps in unit area, kg
Ws - weight of undug onion bulbs collected from the soil in unit area, kg

Field efficiency

The field efficiency is the ratio of effective field capacity to theoretical field capacity of the machine.

Percentage of damaged bulbs

The damage percentage was calculated using the equation given below (Ibrahim *et al.*, 2008).

$$\mathbf{D = (N_d/ N_t) \times 100} \quad \text{..... (7)}$$

Where, N_d is the total number of damaged bulbs,

N_t is the total number of bulbs

From the data collected from each plot, the coverage, cost of harvesting and harvesting efficiency was calculated.

Cost economics

The total cost of the onion digger was arrived and fixed and variable costs for operating the onion digger unit per hour are also calculated. This cost was compared with manual method. Payback period and savings in cost and time using the onion digger was also arrived.

Results and Discussion

Physical properties

The physical properties determined experimentally were the depth of onion, area of onion coverage and shoot height of onion.

From Table 1 it is inferred that the average depth of onion bulb varied from 10 to 16cm.The average shoot height for *Allium cepa* variety varied from 14 to 22cm and the average area of onion bulb coverage varied from 5 to 8cm.

Self-propelled onion digger compared with conventional methods

Manual harvesting of onion is done by use of khurpa or spade which is a labor intensive and time-consuming operation. It is suitable for only small land holders for their own use. The field capacity of manual digging of onion by khurpa is 0.015 ha/h. and it was less than the portable Self-propelled onion digger with field capacity of 0.12 ha/h.

Digging efficiency of self-propelled onion digger

The onion digger was fabricated and was tested by varying the level of factors such as forward speed and depth of operation. The results obtained are discussed in the following sections (Table 2).

Table.1 Depth of onion, shoot height and area of onion coverage

Name of the plot	Height of shoot(cm)	*Area of onion coverage, (cm^2)*	Depth of onion (cm)
Plot 1	15	7.5	**12**
Plot2	18.2	6	**13**
Plot 3	14	8.1	**11**
Plot 4	17	8	**10**
Plot 5	19	6	**15**
Plot 6	20	5	**14**
Plot 7	22	8	**12**
Plot 8	19	7	**12**
Plot 9	16	6.9	**16**
Plot 10	**18**	**8**	**13**

Table.2 Speed of operation and digging efficiency

Speed of Operation(km/h)	Digging efficiency (%)			Average
	Plot1	Plot2	Plot3	
2	97	97.5	97	**97**
2.3	95	95.5	96	**95.5**
2.5	**94**	**94**	**94**	**94**

Table.3 Depth of operation and digging efficiency

Depth of Operation(cm)	Digging efficiency (%)			Average
	Plot1	Plot2	Plot3	
12	90	88	89	**88**
15	92	93	94	**93**
20	**98**	**97**	**99**	**98**

Table.4 Forward speed on percentage of bulb damage

Speed of operation(km/h)	Bulb damage %			Average
	Plot1	Plot2	Plot3	
2	1	2	1	**1.33**
2.3	2	3	3	**2.67**
2.5	**4**	**4**	**3**	**3.67**

Table.5 Depth of operation on percentage of bulb damage

depth of operation(cm)	Bulb damage %			Average
	Plot1	Plot2	Plot3	
12	9	11	13	**11**
15	4	5	4	**4.34**
20	**1**	**2**	**2**	**1.67**

Table.6 Cost economics

Particulars	Self-propelled onion digger	Manual method (Khurpa)
Cost of operation per hectare, Rs.	867	4800
Cost of operation per hour	102	50
Area covered, ha.h^{-1}	0.12	0.01
Time required to cover one hectare	8 and half	96-man hour
Saving in cost, percent	81.9	-
Saving in time, percent	91.3	-

Fig.1 Onion digger-front view

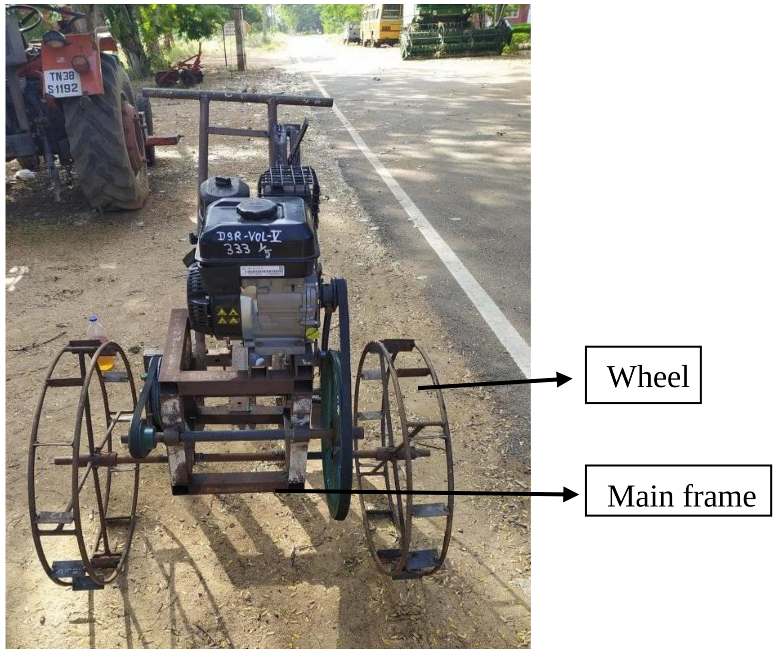

Fig.2 Onion digger-Isometric view

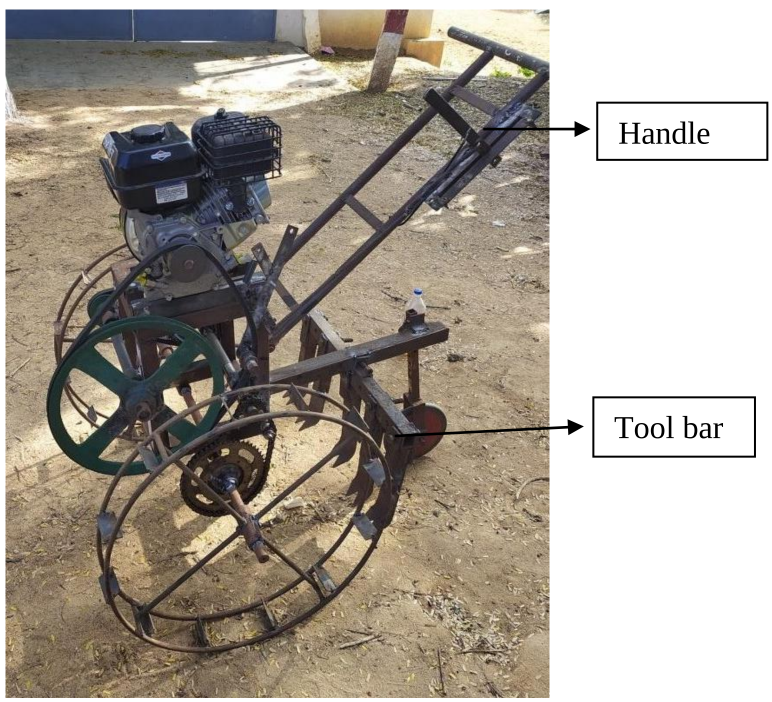

Fig.3 Tool bar with digging blade

Fig.4 Ground wheel

Fig.5 Field preparation

Fig.6 Crop parameter measurement

Effect of forward speed on digging efficiency

The effect of forward speed on digging efficiency was shown in Fig. 2. It is seen that the increase in speed of operation from 2 to 2.5 km/h digging efficiency was decreased. The maximum average digging efficiency of 97 % could be achieved at a forward speed 2 km h^{-1}.

Effect of depth of operation on digging efficiency

From table 3 it is seen that there was a trend of increase in digging efficiency with gradual increase in the depth of operation. The digging efficiency at 12cm depth is 88% and it increases to 93% at 15 cm depth and it is further increased to 98% at 20cm depth of operation.

Percentage of bulb damage of self-propelled onion digger

Effect of forward speed on percentage of onion bulb damage

The effect of speed of operation on percentage of plant damage was shown in table 4, it is seen that there was a trend of increase in percentage of plant damage with gradual increase in the speed of operation. The percentage of plant damage at 2km/h is 1.33% and it is increased to 2.67% at 2.3km/h and it is further increased to 3.67 at 2.5km/h.

Effect of depth of operation on percentage of bulb damage

From table 5 it is seen that there was a trend of decrease in percentage of plant damage with gradual increase in the depth of operation. The percentage of plant damage at 12cm depth of operation is 11% and at 15cm depth of operation is 4.34% and at 20cm depth of operation percentage of plant damage reduces to 1.67% (Fig. 6).

Cost economics

The cost economics of the developed onion digger was worked out and compared with manual digging method (Table 6).

In conclusion, the performance of Self-propelled onion digger was studied and compared with Manual method. The average shoot height was17.82cm and the average area of coverage of onion bulb in soil was7.05cm^2. The maximum digging efficiency 97 % was achieved at forward speed of 2km/h with 20cm depth of operation. The minimum percentage of bulb damage of 1.67 % was achieved at forward speed of 2km/h and at depth of 20cm.The field capacity of the self-propelled onion digger was found to be 0.12ha/h. The saving in cost and time were 81.9% and 91.3% respectively as compared to convention method of onion harvesting.

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