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Development and Evaluation of Tractor Operated Onion Digger

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Authors' contributions

This work was carried out in collaboration among all authors. Author AG performed conceptualization, data collection, writing- original draft preparation. Author PD did the methodology, data collection, writing- reviewing and editing. Authors SVJ and RKN visualization and supervised the work. All authors read and approved the final manuscript.

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ABSTRACT

Onions are cultivated in various regions of India across two to three growing seasons. Ensuring a timely harvest of the onion crop is essential for securing optimal market prices. Delayed harvesting can lead to increased losses due to factors like rain, especially during peak harvest periods. Typically, onion harvesting has been a manual task undertaken by small and medium-sized farmers in Chhattisgarh, India. However, due to the labor-intensive, monotonous, and costly nature of manual harvesting, a tractor-powered onion digger was conceptualised, developed, and subjected to evaluation. This innovative digger comprised distinct units, including a digging mechanism, separator, windrower, and transmission unit. The necessary power to operate this onion digger was calculated to be 14.04 kW. An experimental study was undertaken to optimise

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various parameters, specifically the rake angles (15°, 20°, and 25°) of the V-shaped blade and forward speeds (2.0, 2.5, and 3.5 km/h), concerning essential harvesting factors (such as damage percentage, harvesting efficiency, and separation index) attributed to the developed machine. Remarkably, the harvesting efficiency peaked at 97.02% when utilising a 20° rake angle for the blade at a forward speed of 2.0 km/h. The harvesting of onions with a developed onion digger was also found to be more cost-effective than manual harvesting.

Keywords: Onion harvesting; design of onion digger; harvesting efficiency; separation index; cost of operation.

1. INTRODUCTION

India is the world's most prominent vegetable producer, accounting for over 20% of the country's GDP. India is the second largest onion grower, followed by China with a production of 26.73 MT in 2020 [1], but productivity was lower than other countries as shown in Fig. 1. It's probable that this is related to onion production's low level of mechanization [2]. In India, manual onion harvesting techniques such as *khurpa, kudali* (both are traditional tools), and hand pulling were the most common. It was a long, tedious, difficult, and expensive procedure [3–6]. It's approximately half the cost of cultivating onions, and delays in harvesting due to the unavailability of the workers during the peak time of harvesting are also undesirable for the onion bulb [5] because later-harvested onion bulbs exhibit more skin splitting than earlier-harvested onion bulbs [7]. Agricultural mechanization can reduce operational time and costs in agriculture, while also increasing productivity [8,9]. Khura et al. [10] developed a tractor-drawn onion harvester and the main components of the harvester were digging (a V-shaped blade), conveying and separating units. During field testing, the prototype onion digger with the above-designed components functioned as expected, with a digging efficiency of 97.7%, a separation index of 79.1%, bulb damage of 3.5%, a fuel consumption of 4.10 l h^{-1} and a draught of 1099.25 kg. Khambalkar et al*.* [11] designed an onion harvester that had a working width of 0.6 m and a depth of about 0.1 m and was powered by small tractors with a power range of 10 to 15 kW. The soil mass load on the harvester was worked out to be 1376.62 kg m^{-2}. The volume of soil discharge per second on the web has been estimated to be 0.023 m^3 s^{-1} for a travel speed of 3.0 km h^{-1}. Singh [12] tested the performance of a fabricated onion digger and discovered that operating at a depth of 76.20 mm resulted in no harm to the onion bulbs. The digging efficiency of the developed onion digger was found 89.80% with a harvesting capacity of 2.77 t h^{-1}, which also saves 58% of labor and 49% of the cost. Mehta and Yadav invented an onion harvester that saved 87.64% of the time, 46.23% of the energy and 78.86% of the cost of operation as compared to hand harvesting [4]. According to prior research, the blade rake angle has a substantial impact on digging efficiency. Ibrahim et al*.* [13] set the multi-purpose digger to the test for potatoes at 12°, 18°, and 24° blade rake angles, and the best results were coming from 18°. Similarly, the effectiveness of the Massah et al*.* [14] onion harvester was tested at 12°, 15°, and 20° rake angles, with the 20° rake angle proving to be the most effective and significant effect due to forward speed. It also investigated the root crop harvester's forward speed and found that it was extremely effective at around 2 km h^{-1} [4].

It was reported that Raipur, Durg, Raigarh, Kanker and Surajpur were the five top onion producer districts of Chhattisgarh, India, in 2019-20 [15]. Purposive sampling [16,17] was conducted in 2020–21 to perform a survey in the Chhattisgarh Plain, namely in several blocks in the districts Raipur, Durg, Dhamtari, and Mahasamund, to learn about the region's adopted harvesting methods. Uprooting onion bulbs and using simple conventional tools were the most common methods of onion harvesting in this region. It was revealed from the survey that the use of machinery was quite limited and that there was not a single tractor-driven onion harvester in Chhattisgarh. As per the grower, the available digger isn't adequate for the task in this region. As a result, research was carried out to develop, construct, and test a tractor-drawn onion digger.

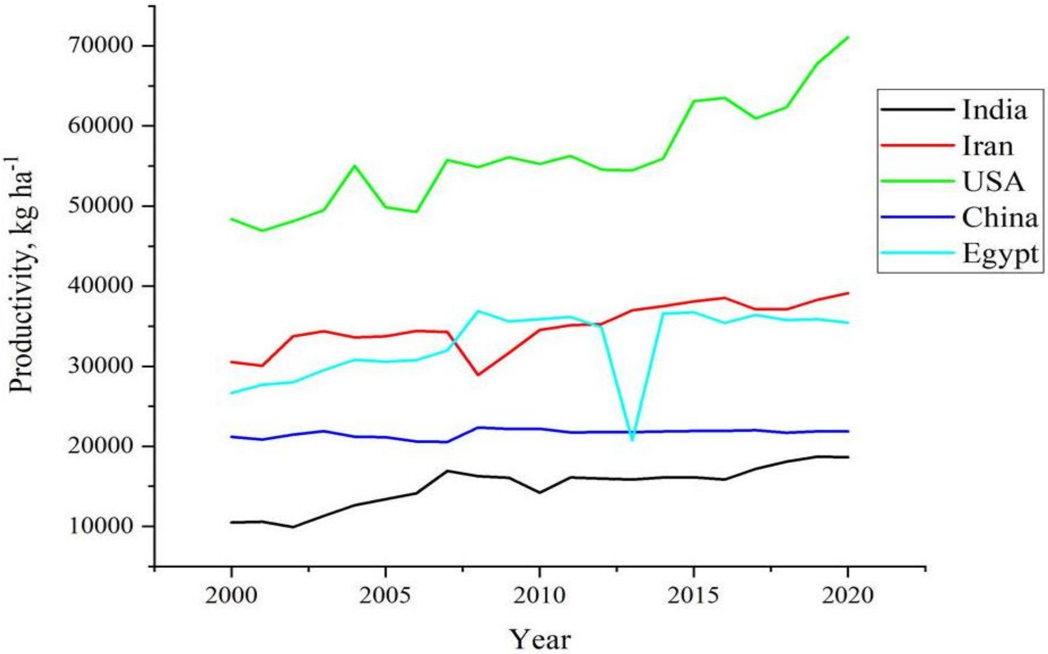

Fig. 1. Productivity of top five onion producing countries (*Faostat*)

2. MATERIALS AND METHODS

An onion digger was designed and developed at the engineering workshop of Indira Gandhi Krishi Vishwavidyalya, Raipur (C.G.) and shown in Fig. 2. Various parameters were considered and measured for the design of the onion digger, *viz.* engineering properties of the onion bulb [18–23], agronomical characteristics of the onion crop [24], soil parameters [25] and various machine components. Understanding crop properties was imperative for crafting an efficient digger. Key factors like row spacing, plant spacing, and onion bulb depth were harnessed to determine machine width, cut depth, and fortify components for robust harvesting. Bulk density analysis of onion bulbs aided in gauging material volume controlled by the separator. Onion bulb mass was pivotal for calculating bulk density, true density, and the interaction of onion mass with machine components, such as the separator, during excavation. Geometric mean diameter guided separator rod spacing, computed using data from polar diameter, equatorial diameter, and thickness measurements of onion bulbs. Measurement of soil attributes encompassing moisture content, bulk density, and soil cone index was significantly influenced blade design for effective soil excavation. The main component of the developed digger is the cutting blade, which is involved in the soil to excavate the onion bulb and convey it to the separator.

2.1 Development of Onion Digger

Based on agronomical parameters, i.e., depth of onion bulb and row spacing, the size of the digger was conceived. The fabrication work and developed onion digger are depicted in Figsl 2 and 3, respectively. The working width of the digging blade was kept at 600 mm, designed to work up to 100 mm depth from the ground surface, as considered by Mehta and Yadav [4]. The required power to operate the onion digger was calculated as 14.04 kW [26–28]. Based on the soil draft working on the digging unit, a 6 mm thick MS sheet (AISI 1018) was used to manufacture the digging blade [29–32], which was easily detachable. Based on the dugout material, a separator unit was designed, which is attached just behind the digging blade [20,28,33]. The rotary power from the tractor PTO was used to drive the separator with the help of the transmission unit, which consists of the PTO bush, universal joint, gearbox unit, and chain drive from the PTO of the tractor to the separator unit as shown in Fig. 4 (in which 1. Gearbox input shaft, 2. Gearbox, 3. Sprocket-56 teeth, 4. Bars, 5. Sprocket-17 teeth, 6. Separator input shaft, 7. Separator, 8. Link attachment chain, 9. Dual chain, 10. Gearbox output shaft). A windrowing unit was attached behind the digger just below the separator to reduce the impact of the sudden fall of onions behind it and also discharge the onions in the centre of the machine. The overall dimension of the developed onion digger was 1500×850×800 mm, which was small enough to reduce the capital cost and make it affordable for small farmers.

2.2 Experimental Design

An experiment was conducted to assess the influence of different rake angles (A) of the blade and forward speed (S) on harvesting parameters (i.e. damage percent, harvesting efficiency, and separation index) of developed onion digger with three levels of each factor (i.e. rake angle 15˚(A1), 20˚(A2) and 25˚(A3) and forward speed 2.0 km h^{-1} (S1), 2.5 km h^{-1} (S2) and 3.0 km h^{-1}(S3)). A split-plot design [34,35] was used to analyze the observed data with the utilization of the OPSTAT statistical package developed by CCS Haryana Agricultural University, Hisar, India. The rake angle was taken for the main plot, and the forward speed was chosen for the sub-main plot. Forward speed was taken for the sub-main plot because it was easier to change the forward speed of operation than the rake angle of the blade. A total of nine treatment combinations (A1S1, A1S2, A1S3, A2S1, A2S2, A2S3, A3S1, A3S2 and A1S3) were observed with five replications of each. The total number of plots was 45 (3^2 × 5, i.e., 3 factors at 2 levels with 5 replications) of size 10 m × 0.6 m in a total of 752 m^2 plots, as depicted in Fig. 5. A developed onion digger was prepared for field evaluation with a V-shape blade and 0.7 m s^{-1} separator velocity. Some crop parameters before harvesting the onion bulb are displayed in Table 1.

Fig. 2. Fabrication of onion digger

Fig. 3. Developed prototype of onion digger

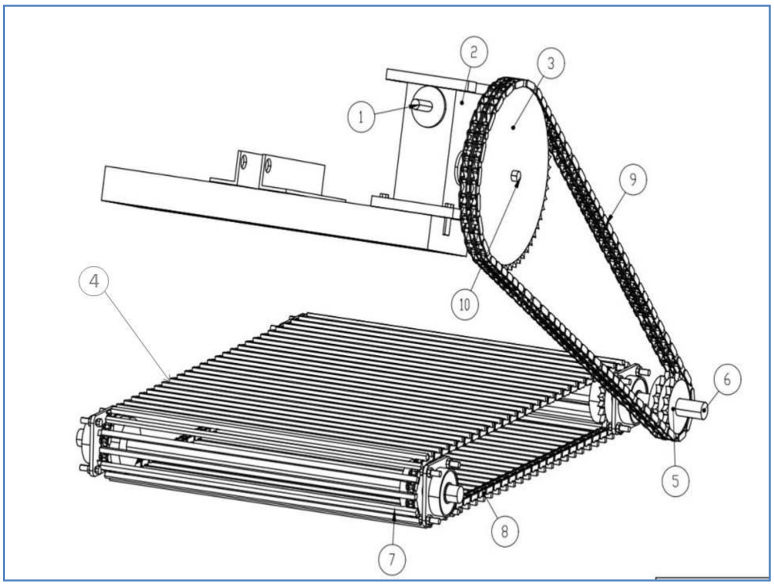

Fig. 4. Layout of transmission system

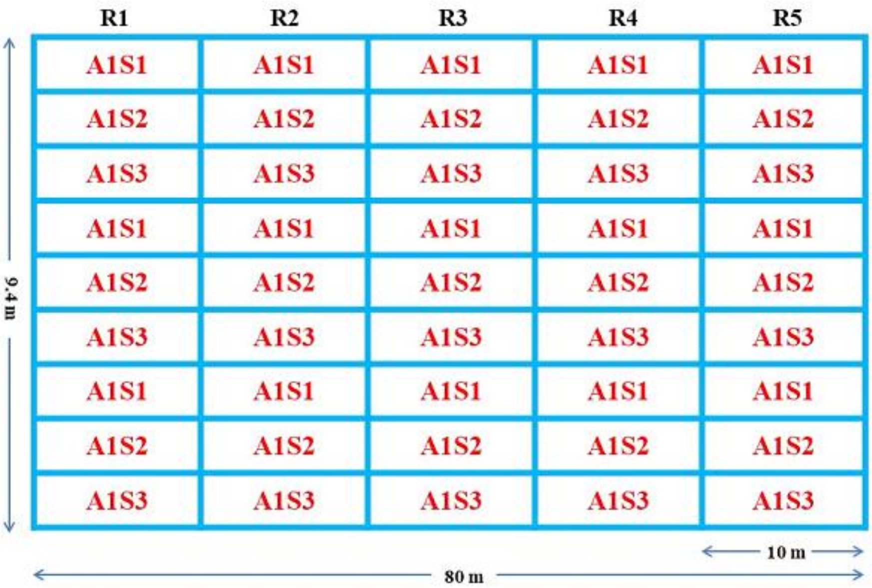

Fig. 5. Field layout

2.3 Performance Evaluation

The performance of the developed onion digger evaluated based on its damage percent, harvesting efficiency and separation index. Damage percent is the ratio of damaged onion bulbs to the total collected onion bulbs in a 10-meter strip of the run. Digging efficiency is the ratio of the onion plant successfully harvested to the total number of onion bulbs available in a 10-metre strip after digging with a developed onion digger. When the harvesting efficiency was computed, the damage percent was subtracted from the digging efficiency. After separation, the whole dugout material was gathered by running the digger at a 10 m strip by placing the carpet (collector) rear end just behind the separator and calculated in percent using Eq. 1 [4,20].

$$\text{Soil separation index (\%)} = \frac{W_t - W_a}{W_t} \times 100 \quad \ldots 1$$

Where,

W_a = Actual weight of soil and onion bulbs collected at the rear end of the soil separator, kg; and

W_t = Theoretical weight of soil cut by blade along with an onion bulb at a working depth of operation, kg.

The actual area covered while operating the developed onion digger in a specific time period was assessed and defined as the effective field capacity, measured in hectares per hour [36]. The experiment field and operation of the developed digger are depicted in Figs. 6 and 7.

Table 1. Crop parameters before digging operation

S.No.	Parameters	Values
1	Variety	N-53
2	Period of crop, days	110-130
3	Sowing method	Transplanting
4	Row spacing, mm	150.40±2.43
5	Plant spacing, mm	100.70±3.61
6	Height of plant (90 DAT), mm	583.90±26.79
7	No. of leaves per plant (90 DAT)	10.20±0.76
8	Plant population (90 DAT)	49.20±0.87
9	Depth of onion bulb, mm	57.60±3.63
10	pH	6.74±0.17
11	Temperature, °C	41.30±1.01

DAT= days after transplanting, ± values are the 95% confidence interval from sample mean

Fig. 6. Experimental field

Fig. 7. Operation of developed onion digger

2.4 Cost Analysis

The cost of operation of the developed onion digger was calculated using IS: 9164. The developed onion harvester's operational cost was divided into fixed and variable costs. The depreciation, interest on the capital cost, shelter, insurance, and taxes were taken under fixed costs, and variable costs include fuel, lubricants, repair-maintenance costs, and wages of labour [37,38]. The cost of the developed onion digger was calculated at ₹ 28,120/- based on the cost of components and fabrication charges (Table 2). The breakeven point [39] and payback period [40] were also measured of the developed machine by using Eq. 2 to Eq. 5. The expected life of the digger was considered to be 8 years with 250 hours of annual use. Salvage value, rate of interest, and labour required were considered 10% of the initial cost, 10% per annum, and 01, respectively. Then diesel cost, fuel consumption, lubrication cost, repair and maintenance cost, and shelter tax were taken as 95 ₹ l^{-1}, 2.1 l h^{-1}, 20% of fuel cost, 5% of initial cost, and 2% of initial cost, respectively.

$$\mathrm{BEP} = \frac{\mathrm{FC}}{CH - C} \qquad \ldots 2$$

Where,

BEP = Breakeven point, h y^{-1};
FC = Annual fixed cost, ₹ y^{-1};
C = Operating cost, ₹ h^{-1}; and
CH = Custom hiring charges,
₹ h^{-1}. = (C + 25 per cent over head) + 25 per cent profit over new cost

$$\mathrm{PBP} = \frac{\mathrm{IC}}{ANP} \qquad \ldots 3$$

Where,

PBP = Payback period, year;
IC = Initial cost of machine, ₹;
ANP = Average net annual profit, ₹ y^{-1}.

$$\mathrm{ANP} = (CH - C) \times AU \qquad \ldots 4$$

$$\mathrm{AU} = AA \times EC \qquad \ldots 5$$

Where,

AU = Annual use, ha y^{-1};
AA = Average annual use, h y^{-1}, and;
EC = Effective field capacity, ha h^{-1}.

Table 2. Cost of developed onion digger

S.No.	Parameters	Price, ₹
1.	Frame	3,600.00
2.	Blade	1,600.00
3.	Transmission system	
	a. Gear box	2,225.00
	b. Chain drive	
	c. Sprocket 2	350.00
	d. Sprocket 3	635.00
	e. Chain 1	4,000.00
	f. Bearing	1,600.00
	g. Idler	300.00
4.	Separator	
	a. Link attachment chain	3,500.00
	b. Shaft 1	465.00
	c. Shaft 2	425.00
	d. Sprocket 1	920.00
	e. Rod	600.00
5.	Universal joint	800.00
6.	Windrowing	900.00
7.	Wheel	1,200.00
8.	Labour charges	5,000.00
9.	Total cost	28,120.00

3. RESULTS AND DISCUSSION

There was a considerable variation in damage as a result of factors A and S, as well as their interaction. As shown in Table 3, the most effective result was observed due to A2 and S1 on damage percent, and their interaction was also observed at a minimum of about 2.74%, as depicted in Table 4. When the angle of the cut was changed from 15° to 20°, the damage percentage fell by 90.43 %. There was a further increase of 61.17 % when the angle was adjusted from 20° to 25°. It might be caused by a short depth of cut of around 50 mm at A1, causing bigger onion bulbs to come into contact with the blade before being entirely dug out. As a result, the lower section of the onion bulb stayed in the soil, and the blade did not reach the bottom of the onion bulb and cut it. In the case of A3, the digging depth was greater, resulting in uneven digging depth over the length of the cultivated strip, and bigger soil clods with a larger volume caused damage to the onion bulbs. Due to forward speed, better performance was observed at lower speed S1 with an average digging efficiency of 4.14%, and it was observed that as the forward speed increased, damage also increased. The volume of soil and onion bulb to be handled increased as the digger's forward speed increased, causing friction between soil clods and the bulb that increased the digger's damage percentage.

It was observed that harvesting efficiency was found to be maximum due to A2 (96.60%) and S1 (95.62%), as depicted in Table 2, and their interaction effect also showed a significant effect on harvesting efficiency, as shown in Table 3. It was mainly affected by the damage percentage, so as bulb damage decreased, harvesting efficiency improved, so it was easy to correlate harvesting efficiency with damage percentage.

Among the different rake angles, the maximum separation Index was observed to be 57.21% at A1, and due to forward speed, it was observed to be 58.26% at S1. It happened because higher soil masses were handled at a higher rake angle because of deep penetration, which made separation difficult. And also, the removal of material from the separator to the rear end was quick at higher speeds, so the separation was not done properly at higher speeds. As a result, the separator worked effectively at a lower speed of 2.0 km h^{-1}.

The capital cost of the machine was evaluated by considering the price of different components and fabrication charges. The cost of one unit of the prototype onion digger was calculated at ₹ 28,120/-. The cost of operation was calculated ₹ 3,461.26/- per hectare with an average effective field capacity of 0.12 ha h^{-1} at 2.0 km h^{-1} forward speed. The developed onion digger's breakeven point (92 h per year) and payback period (0.53 year) were calculated, as depicted in Fig. 8. These metrics assess equipment efficiency and financial viability. The breakeven point is when digger gains match costs, with 92 hours per year indicating benefits exceeding development expenses. The payback period (0.53 years) signifies operational gains covering creation and deployment costs in slightly over half a year. It was concluded that a small power tractor-operated onion digger cum separator was successfully developed, and the best outcome was observed with a V-shape blade at a rake angle of 20° and a forward speed of the onion digger of 2.0 km h^{-1} with 97.02% harvesting efficiency.

Table 3. Mean value of the harvesting parameters of developed onion digger

Factors	Damage, %	Harvesting efficiency, %	Separation index, %
Rake angle (main-plot)			
A1	6.92±0.57	92.82±0.58	57.21±1.71
A2	3.16±0.30	96.60±0.29	56.22±1.87
A3	4.40±0.69	95.39±0.69	52.26±1.77
SE(m)	0.149	0.146	0.299
CD	0.492	0.483	0.989
Forward speed (sub-plot)			
S1	4.14±0.80	95.62±0.80	58.26±1.88
S2	4.22±0.78	95.57±0.78	55.24±1.38
S3	6.11±0.99	93.63±1.00	52.19±1.69
SE(m)	0.052	0.052	0.517
CD	0.154	0.153	2.183

SE(m) = Standard error of the mean, CD= Critical Difference, ± values are the 95% confidence interval from sample mean

Table 4. Effect of rake angle of blade and forward speed on damage, harvesting efficiency and separation index of the developed onion digger

Treatments	Damage, %	Harvesting efficiency, %	Separation index, %
A1S1	6.71±0.40	93.55±0.39	60.41±1.88
A1S2	5.84±0.41	93.54±0.40	56.91±2.25
A1S3	8.31±0.49	91.37±0.48	54.32±2.04
A2S1	2.57±0.30	97.02±0.29	60.11±2.54
A2S2	2.60±0.31	96.85±0.30	54.95±2.09
A2S3	3.55±0.32	95.94±0.31	53.61±1.86
A3S1	3.98±0.31	96.29±0.30	54.26±2.01
A3S2	3.73±0.21	96.32±0.19	53.87±2.46
A3S3	6.69±0.40	93.57±0.38	48.64±1.96
SE(m) (S at same level of A)	0.257	0.253	0.517
SE(m) (A at same level of S)	0.166	0.163	0.663
CD (S at same level of A)	0.294	0.291	2.183
CD (A at same level of S)	0.537	0.528	1.996

SE(m) = Standard error of the mean, CD= Critical Difference, ± values are the 95% confidence interval from sample mean

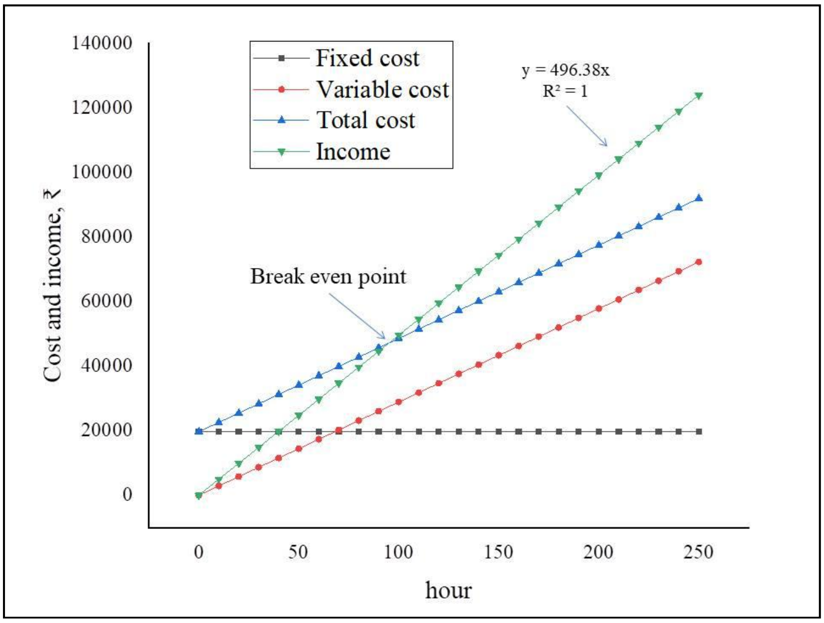

Fig. 8. Break even point of developed onion digger

4. CONCLUSION

Various design parameters, like agronomical parameters, soil properties, and machine components, were determined in field and laboratory conditions and applied to the design of the onion digger. A tractor-drawn onion digger was designed and developed successfully in the Department of Farm Machinery and Power Engineering, IGKV, Raipur. The best result was found with a rack angle of 20° at a forward speed of 2.0 km h^{-1}. The developed onion digger could harvest a maximum of 3.11 t h^{-1}. The cost of the machine and the cost of operation were found to be ₹ 28,120/- and ₹ 3,346.72/-, respectively.

CONFERENCE DISCLAIMER

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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