TESTING OF MINI-TRACTOR OPERATED COLEUS DIGGER

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Abstract - *Solenostemonrotundifolius, commonly known as coleus/ Chinese potato/ hausa potato is an under exploited minor tuber crop grown extensively in several parts of India. Manual harvesting involves digging out the tubers using spades and forks which is found to be time consuming and tedious. A coleus digger attached to a mini tractor was developed and its performance was tested in the instructional farm, KCAET, Tavanur. The performance of the digger was tested for various parameters such as time of operation and harvesting capacity. The independent variables selected were operating speed and depth of operation. Determination of percentage of damage of the coleus tubers and the field efficiency were also carried out. The results were analyzed statistically using two-way analysis of variance. It was inferred that different operating speed and depth of operation had a significant effect on the time of operation of the digger. However, the harvesting capacity showed little effect on the selected variables. The percentage of damage of coleus was negligible and the field efficiency was found to be 89 per cent. Cost analysis was also carried out for the mini tractor operated coleus digger based on the total cost of materials and labour requirements. There was a saving of 40 per cent in cost for the digger in comparison with manual harvesting*.

Key words: **Mini-Tractor, Coleus Digger, Coleus, Oscillating fingers, power take-off unit**

1. INTRODUCTION

Agriculture contributed to 17.4% to India's GDP with the annual food grain production of around 253.16 MT, recording an increase of 1.14 MT as compared to 2014-15 (Anon., 2016). Among the wide varieties of food crops cultivated in India, root and tuber crops become the most significant crops after cereals. They find an important place in the dietary habits of small and marginal farmers, especially in the food security of tribal population. *Solenostemonrotundifolius,* commonly known as coleus. One among the minor tuber crops, which is being extensively cultivated in some parts of India since past few years. Farmers usually grow the tubers on raised beds in fields. Traditionally, coleus is harvested when haulms dry up, i.e., 4 to 6 months after planting. This is done manually by digging out the soil containing tubers using hoes, forks, spades and other conventional tools followed by their separation and collection. This has been found to be a tedious, hectic, laborious and time-consuming practice. It also required proper handling to avoid cuts, breakage, bruises and injury. To overcome these setbacks farmers, tend to adopt alternative method of mechanical harvesting (Younus, 2014).

Mechanical harvesting of root crops involves digging out the tubers using implements which are attached to a prime mover. The prime mover can be a power tiller, tractor, etc. A mechanical coleus harvester must ensure the quality of tubers during operation. It must also be less time consuming and must have higher efficiency of performance. No specific mechanical harvesting technique has been completely successful for coleus, contradictory to other root crops such as potato and cassava.

Various models of coleus harvesters were developed in KAU. A mini tiller operated coleus harvester developed at KCAET was studied and its performance was analyzed. It consisted of a rotary slasher and a cutter bar assembly. There were several problems associated with its construction. The harvester had the following disadvantages:

- The rotating element created high vibration resulting in scattering of the uprooted tuber.
- Non-detachment of the clumps hence it couldn't be used for beds having height more than 30 cm, low ground clearance.

Chamen*et al.* (1979) developed a high output rotary digger capable of working in heavy soils. The most important design variable selected was bite length (250 mm) which was determined by a subjective assessment over a number of years and on a range of soils. The most effective rotor design to provide the required bite length was 4 L- shaped blades bolted on flanges.

Al- Jubouri*et al.* (1984) developed a theory for a vibratory potato digger that employed orbital vibrations. The prototype was extensively tested in ridged fields at a forward speed of 3 kmph and a digging depth of 200 mm. The draught force- velocity ratio was satisfactory but poor agreement was obtained between predicted and experimental power ratios.

Obigol*et al.* (1986) developed a prototype of single row model-2 cassava harvester. Its design involved two rows of reciprocating P.T.O. driven diggers. It dug two opposite sides of the ridge from the furrow bottom to uproot cassava tubers. The design of the gang of digger ensured a clean harvesting operation by minimizing damage to the harvested tubers. It left a well pulverized row with good tilth. The harvester operated at a forward speed of about 2.5 kmh^{-1} to 4 kmh^{-1} and harvesting rate was 0.25 to 0.4 ha h^{-1}.

Objective of research is to test the performance of the mini tractor operated coleus digger.

2. Materials and Methods

In this study it was aimed to test a mini tractor driven coleus digger shown in **Fig.2.A** to harvest coleus tubers shown in **Fig.2.B** grown in raised beds. Earlier, a mini power tiller operated coleus harvester was field tested and performance was evaluated. However, it had several disadvantages associated with its construction. This was because it used a rotary slasher which created excessive vibration. This caused the tubers to scatter in the field which was inconvenient for the farmers to collect. Also, it caused damage to the coleus and thus yield was reduced. Accordingly, the prototype of TNAU model ginger harvester was studied and was modified to make it suitable for harvesting coleus.

Fig.2.A

Fig.2.B

2.1 Site preparation

The field was divided into two equal plots of 0.036 ha each. In each plot, beds of sizes 30 m x 0.5 m respectively as length x breadth were prepared. The height of the bed selected was 30 cm shown in **Fig.2.C** A water channel was made in the middle of the field to ensure drainage of the study area.

Fig.2.C

2.2 Working of Coleus digger

The tractor p.t.o provides a rotational speed of 540 rpm which was reduced to 340 rpm by using the gear box. Reduction in rpm was required since higher rpm caused damage to the components. This reduced rpm was transferred to the cam drive through the output shafts. The cam drives and the connecting rods provided the required oscillatory motion to be imparted to the oscillating fingers.

During operation, the two sets of oscillating fingers, hinged at the outer ends oscillated vertically while the share penetrated into the soil up to the root depth of the tubers and uprooted them. Due to the forward motion of the implement, the soil lump containing the tubers moved towards the fingers, where they got separated. Also, the fingers broke the soil lumps and deposited the tubers on the bed along the length. The side fingers with the land sides prevented the scattering of the mass side-ward.

2.3 Selection of variables

Several parameters such as bed width, bed height, operating speed and depth of operation affected the performance of the digger for uprooting the tuber from soil. The bed width and height were kept the same for all the beds. Testing was carried out in two different speeds and operating depths. The speed of operation was varied at 1.0, 1.5 and 2.0kmh^{-1}. The depth of operation selected were 10 cm and 15 cm. These parameters were optimized to achieve maximum efficiency of the digger in the laterite soil for a bed width of 60 cm and a bed height of 30 cm.The observations were statistically analysed using two-way analysis of variance using F- test. The various factors and their levels are furnished in the **Table 1.**

Table 1 Factors selected for two-way analysis of variance

Soil type	Bed width (cm)	Bed height (cm)	Speed of operation (kmh^{-1})	Depth of operation (cm)
Laterite	60	30	1	10
			1.5	20
			2	
Replications - 3				

Total number of treatments = 1 x 1 x 3 x 2 = 6

Total number of experiments = 6 x 3 = 18

2.3.1 The speed of operation

It determines the thrust acted on the finger assembly exerted by the soil mass and the uprooted coleus. The tuber yield obtained also varied with the change in the speed of operation. Three speeds were selected, viz., 1.0kmh^{-1}, 1.5 kmh^{-1} and 2.0 kmh^{-1} respectively.

2.3.2 The depth of operation

It affects the draft of the implement and the performance of the machine. Various levels of depth of operation were selected viz., 10 and 15 cm for the study.

2.4 Performance evaluation

The performance of the tractor operated coleus digger shown in **Fig.2.D** was evaluated in the experimental plot in the instructional farm of K.C.A.E.T, Tavanur during the month of November. The testing was carried out for the determination of time of operation and harvesting capacity with respect to various independent parameters. The parameters selected were respectively speed of operation viz., 1.0, 1.5 and 2.0kmh^{-1} and depth of operation viz., 10 and 15 cm. The actual field capacity, theoretical field capacity, field efficiency and percentage of damage of the coleus were calculated using standard procedures.

Fig.2.D

2.4.1 Time of operation

The time taken to operate the machine for different speeds of operation and depths of were observed using a stop watch. The results were statistically analysed using two-way ANOVA. Shown in chart.2.1 and chart.2.2

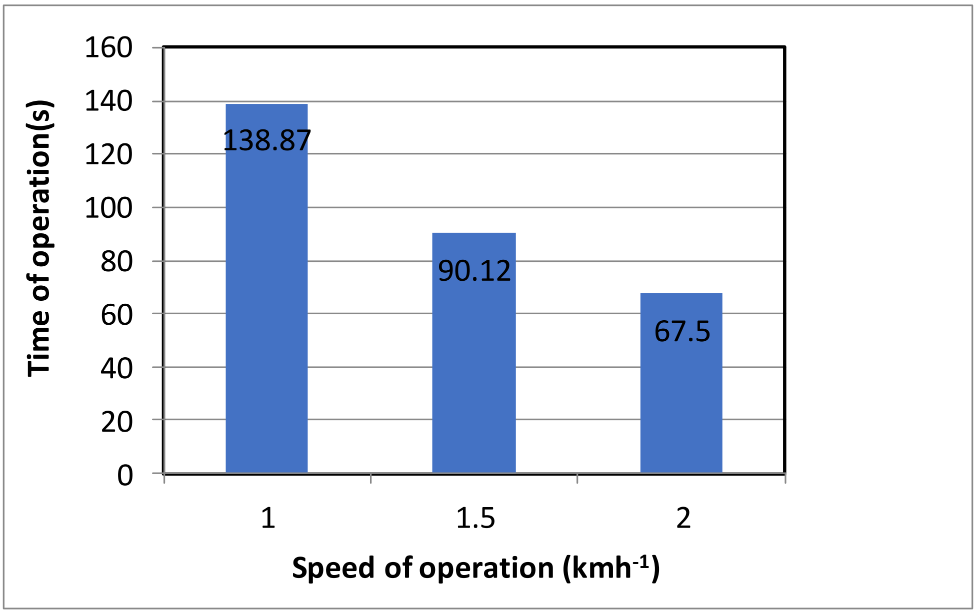

Chart 2.1 Variation of time of operation with respect to speed of operation.

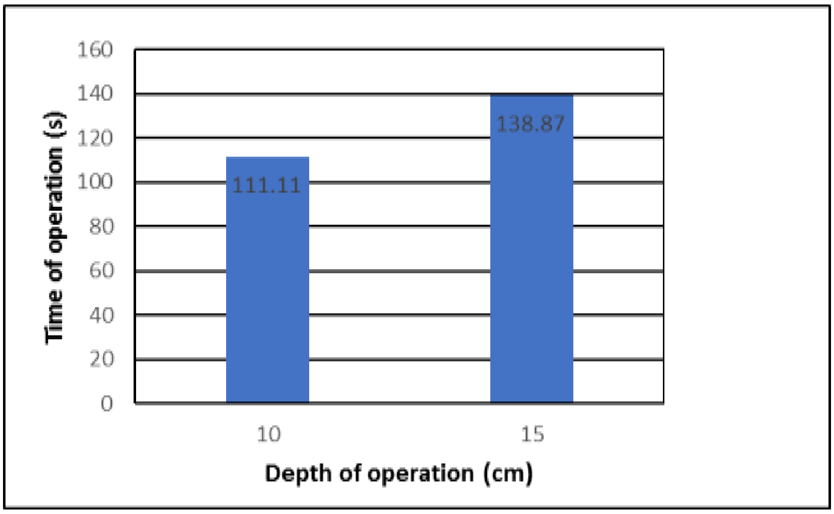

Chart 2.2 Variation of time of operation with respect to depth of operation

2.4.2 Harvesting capacity

The harvesting capacity of the implement was determined by weighing the total amount of coleus collected after operation and dividing by the total time of operation. The results were statistically analyzed using two-way ANOVA. Shown in Chart 2.3 and Chart 2.4

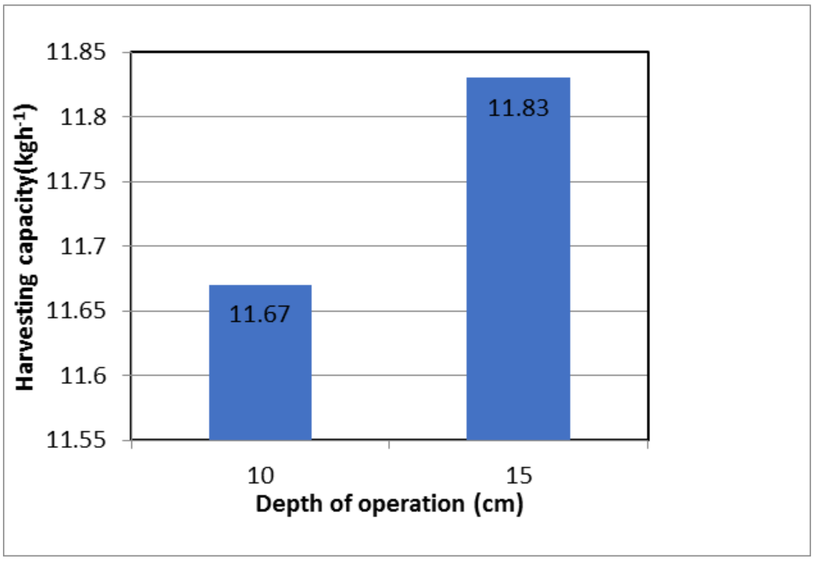

Chart 2.3 Variation of harvesting capacity with respect to depth of operation

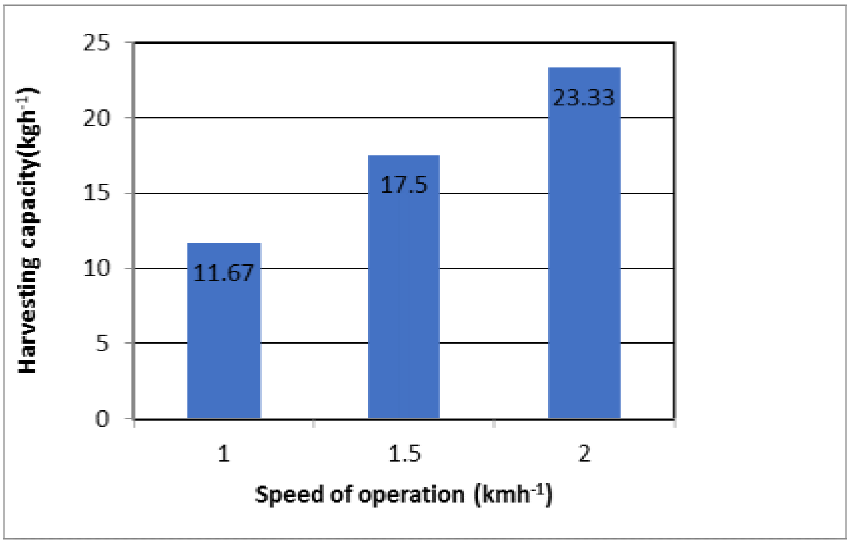

Chart 2.4 Variation of harvesting capacity with respect to speed of operation

2.4.3 Damage

It represented the damage of the tubers occurring due to cutting by blade or bruising during the harvest. According to farmers, damage to the coleus occurred when the whole roots did not come out while harvesting, which was unsuitable for selling. After harvesting, damaged tubers were separately weighed using an electronic weighing balance. The percentage of damage of coleus during the operation was calculated by the equation:

$$Damage\ (\%) = \frac{Mass\ of\ damaged\ coleus\ (kg)}{Total\ yield\ (kg)} \times 100$$

2.4.4 Field efficiency (FE)

It is the ratio of theoretical field capacity to the actual field capacity. Actual field capacity (AFC) was determined by recording the time taken to harvest a predetermined specified area. The theoretical field capacity (TFC) was calculated as per the equation,

$$TFC = \frac{SW}{10000} \text{ha h}^{-1}$$

S = Speed of operation of machine, m.h^{-1}

W = Width of operation of machine, m

Field efficiency (FE) in percentage;

$$FE = \frac{AFC}{TF.1/C} ⍰ 100$$

Based on the materials used and the labour requirement for the fabrication of the coleus harvester, the cost of operation was calculated. The saving in cost in the field operation with coleus harvester was worked out in comparison with the conventional method of harvesting coleus. The capacity of the manual labourers for the harvesting (man-hours ha^{-1}) was determined by recording the total time taken to harvest the coleus.

3 Results and Discussion

The field performance of coleus digger was evaluated at Instructional Farm, KCAET, Tavanur during November 2017. The field testing of the digger was conducted to find out time of operation, fuel consumption and harvesting capacity with respect to operating speed and depth of operation. The results for different levels of the parameters were statistically analysed. The performance of damage and field capacity were also determined.

3.1 Time of operation

The observations for the time taken to uproot the coleus with respect to the operating speed and depth of operation is given below

Time of operation (s)

Depth of operation (cm)	Speed of operation (kmh^{-1})								
	1 kmh^{-1}			1.5 kmh^{-1}			2 kmph^{-1}		
10 cm	110.73	115.31	107.29	72	73.41	70.92	50	54	58
15 cm	140.28	139.49	136.84	92.35	89.5	88.51	68.31	66.9	67.29

Sample calculations: F test (two-way ANOVA)

Let H_0: The treatments have no effect on the time of operation

H_1: The treatments have significant effect on the time of operation

(i) T = sum of all observations
= 111.1 + 72.11 + 54 + 138.87 + 90.12 + 67.5
= 533.7

(ii) N = total number of observations = 6

(iii) TSS = sum of squares of all observations $-\frac{T^2}{N}$

$$= \sum x_i^2 - \frac{T^2}{N}$$

$$= 111.1^2 + 72.11^2 + 54^2 + 138.87^2 + 90.12^2 + 67.5^2 - \frac{533.7^2}{6}$$

= 4949.185

(iv) SST = sum of square due to treatments

$$= \left(\frac{(\sum x_1)^2}{n_1} + \frac{(\sum x_2)^2}{n_2} + \cdots - \left(\frac{T^2}{N}\right)\right)$$

$$= \frac{(111.1 + 138.87)^2}{2} + \frac{(72.11 + 90.12)^2}{2} + \frac{(54 + 67.5)^2}{2} - \frac{533.7^2}{6}$$

= 4310.3119

(v) SSB = sum of squares due to blocks

$$= \left(\frac{(\sum x_1)^2}{n_1} + \frac{(\sum x_2)^2}{n_2} + \cdots - \left(\frac{T^2}{N}\right)\right)$$

$$= \frac{(111.1 + 72.11 + 54)^2}{3} + \frac{(138.87 + 90.12 + 67.5)^2}{3} - \left(\frac{533.7^2}{6}\right) = 585.7$$

(vi) SSE = sum of squares due to error

$$= TSS - (SSB + SST)$$

= 4949.185 - (585.7 + 4310.3119) = 53.17

(vii) b = no. of blocks

(viii) t = no. of treatments

(ix) MST = mean square due to treatments

$= \frac{SST}{no.of\ treatments - 1}$

$= \frac{4310.31}{3-1} = 2155.2$

(x) MSB = mean square due to blocks

$= \frac{SSB}{no.of\ blocks - 1}$

$= \frac{585.7}{2-1} = 585.7$

(xi) MSE = mean square due to error

$= \frac{SSE}{(b-1)(t-1)}$

$= \frac{53.17}{1 \times 2} = 26.585$

(xii) Calculated values

$F_T = \frac{MST}{MSE}$

$= \frac{2155.2}{26.585} = 81.06$

$F_B = \frac{MSB}{MSE}$

$= \frac{585.7}{26.585} = 22.03$

From statistical table,

$F_T = F_{(t-1)\ (t-1)\ (b-1))} = F_{(2,2)} = 19$ and

$F_B = F_{(b-1,\ (t-1)\ (b-1))} = F_{(1,2)} = 18.51$

Here the calculated value of F_T and F_B are greater than the table value. Therefore, reject H_0 and accept H_1.

The analysis based on these observations was carried out by two-way analysis of variance using F-test. The ANOVA table showing the calculation results are shown in **Table 3.1**. The detailed procedure of the statistical analysis is presented in above data. The results inferred that more the operation in progressive depths, more time for uprooting than shallow depths. This may be due to more resistance offered by the soil at larger depths.

Table 3.1 ANOVA for the effect of speed and depth of operation on time of operation (s)

Source	DF	SS	MSS	F_c	F_t
Speed of operation(kmh^{-1})	2	4310.3119	2155.2	81.06	19.00
Depth of operation (cm)	1	585.7	585.7	22.03	18.51
Error	2	53.17	26.585		
Total	5	4949.185			

CV = 0.3229 Level of significance = 5%

The operating speed also had a direct influence on the time of operation. Higher speed offered less time to uproot the coleus. It was also inferred that the time taken for operation was maximum when the digger was operated at 1.0 kmh^{-1} and a depth of 15 cm. The minimum time was taken at a speed of 2.0 kmh^{-1} and a depth of 10 cm. However, the yield of operation varied with variation in speed and depth.

3.2 Harvesting capacity

The harvesting capacity of the tractor driven coleus digger was the weight of the uprooted coleus with respect to the time taken for each operating speed and depth of operation. The observations for the harvesting capacity for the operating speed of 1.0, 1.5 and 2.0 kmh^{-1} and for the depths 10 and 15 cm were recorded and statistically analysed using two-way analysis of variance. The result of the analysis is shown **Table 3.1**

Table 3.1 ANOVA for the effect of speed & depth of operation on harvesting capacity (kgh^{-1})

Source	DF	SS	MSS	F_c	F_t
Speed of operation (kmh^{-1})	2	1293.421	646.74	2.00	19.00
Depth of operation (cm)	1	331.229	331.229	1.02	18.51
Error	2	0.0034	0.0017		
Total	5	0.029			

CV = 0.2732 Level of significance = 5%

The results showed that the harvesting capacity did not have any considerable variation with respect to the operating speed of 1.0, 1.5 and 2.0 kmph. The effects of the treatment of operating width on the harvesting capacity were also not significant. This is inferred from the fact that the calculated F- value is lesser than the F- value from the statistical table for 5 per cent level of significance. There was only a little change in the harvesting capacities obtained at the depths of 10 and 15 cm.

Thus, it was observed that both the operating speed and the depth of operation did not influence the harvesting capacity of the coleus digger. This may be due to the inherent characteristics of the tubers. The tubers do not penetrate deeper into the soil. Hence negligible number of tubers may be present at depths more than 15 cm.

3.3 Percentage of Damage

The damaged coleus was identified as those with cuts, bruises and damages that make them unsuitable to be sold. Under these conditions, it was found out that the number of damaged coleus collected were negligibly small. It was almost one damaged among 100 tubers collected (1%). Also, the scattering of the tubers away from the bed was also found negligible. This clearly indicated that the mini tractor operated coleus digger did not produce damaged coleus. This may be due to the oscillatory motion of the implement which produced lesser impact on the coleus than due to its rotary motions.

3.4 Field efficiency

The field efficiency of the mini tractor operated coleus digger was the ratio of the actual field capacity to the theoretical field capacity. The actual field capacity was calculated by determining the total area harvested and the total time taken for the harvest. It was observed that the total time taken to harvest an area of 0.0072 ha was 0.19 hours. Hence the actual field capacity of the digger was found to be 3.65 x 10^{-2} ha h^{-1}. The theoretical field capacity was determined as explained in section 2.2. It was found to be 4.1 x 10^{-2} ha h^{-1}. The calculation of the field efficiency is presented in Appendix VIII. The field efficiency of the digger was found out as 89 per cent.

3.5 Cost economics

The field capacity of the coleus digger was found out as 0.0365 ha h^{-1}. The manual harvesting of coleus was carried out using spades. At the present wage rate of Rs 650 per day, the total cost of operation of harvesting by manual method is Rs

31,250 per hectare. By mechanical harvesting using the mini tractor driven coleus digger, the total cost of operation was estimated as Rs 16,400 per hectare. Hence the savings on harvesting by tractor operated coleus digger over the conventional method was found to be about Rs 14,850 per hectare. The detailed cost analysis of the coleus digger is given

Cost analysis of the mini tractor operated coleus digger.

1. **Mini tractor (VST MT 224)**

A. Basic information

(i) Cost of the mini tractor, Rs	:	370000
(ii) Useful life, year	:	10
(iii) Hours of use per year	:	400
(iv) No. of skilled labours required	:	1
(v) Rate of interest	:	10%
(vi) Salvage value (10% of investment cost)	:	37000
(vii) Field capacity of coleus harvester, ha h^{-1}	:	0.0365
(viii) Fuel requirement, l h^{-1}	:	2.2

B. Various costs

I. Fixed cost

II. (I) Depreciation cost per year, Rs : $\frac{initialcost - salvagevalue}{usefullife}$

: $\frac{370000 - 37000}{10} = 33300$

(ii) Interest on investment per year, Rs : $\left(\frac{(costofminitractor + salvagevalue)}{2}\right) x interestrate$

: $\left(\frac{370000+37000}{2}\right)$ x 0.10 = 20350

(iii) Taxes, insurance and sheltering per year : (cost of mini tractor) x 0.03

: 11100

(iv) Total fixed cost per year, Rs : 33300 + 20350 + 11100

: 64750

(v) Total fixed cost per hour, Rs : $\frac{Totalfixedcostperyear}{hoursofuseperyear}$

:161.8

III. Variable cost

IV. (I) Repair and maintenance per hour, Rs: $\frac{costofminitractor \text{x } 0.05}{400}$

: $\frac{370000 \text{x } 0.05}{400} = 46.25$

(ii) Fuel cost per hour, Rs : Fuel requirement x rate of fuel

	: 148.5
(iii) Cost of lubricant per hour, Rs	: Fuel cost x 0.30
	: 44.5
(iv) Labour cost per hour, Rs	: 150
(v) Total variable cost per hour, Rs	: 148.5 + 44.5 + 150 + 46.25
	: 389.25
V. Total cost per hour, Rs	: Fixed cost + variable cost
	: 162 + 389.25 = 551.25

2. Coleus digger

A. Basic information

(I)	Cost of the coleus digger, Rs	: 45,000
(ii)	Useful life, year	: 10
(iii)	Hours of use per year	: 200
(iv)	Rate of interest	: 7 %
(v)	Salvage value (10 % of investment cost)	: 4500
(vi)	Field capacity of coleus digger, ha h⁻¹	: 0.0365

B. Cost calculation.

I. Fixed cost

(I) Depreciation cost per year, Rs : $\frac{initialcost - salvagevalue}{usefullife}$

: $\frac{45000 - 4500}{10}$

: 4050

(ii) Interest on investment per year, Rs : $(\frac{initialcost + salvagevalue}{2})$ x Interest rate

: $\frac{45000+4500}{2}$x 0.07

: 1732.5

(iii) Taxes, insurance and shelter per year, Rs : cost of implement x 0.03

: 45000 x 0.03

: 1350

(iv) Total fixed cost per year, Rs : 4050 + 1732.5 + 1350 = 7132.5

(v) Total fixed cost per hour, Rs : $\frac{fixedcostperyear}{workinghoursperyear}$

	: $\frac{7132.5}{200} = 36$
II. Variable cost	
(I) Repair and maintenance per hour, Rs	: $\frac{45000}{200} x\ 0.05 = 11.25$
III. Total cost per hour, Rs	: Fixed cost + variable cost
	: 36 + 11.25 = 47.25
Total cost per hectare, Rs	: $\frac{totalcostperhourforcoleus\ uprooter + minitractor}{fieldcapacity}$
	: $\frac{47.25+551.25}{0.0365} = 16397.26$
Round to the value, Rs	: 16,397.00
Cost for manual harvesting	= Rs 12,500 per acre
Total manual cost per hectare	= Rs 31,250

Younus (2014) modified and tested a self-propelled coleus harvester attached to a mini tiller. The digger pierced at a depth of 10 -15 cm to dig out the rhizomes that lie inside the soil. The scattered soil lying in the raised beds were then collected easily. They reported that the excessive vibrations of the slasher caused high percentage of damage to the tubers. Where he expressed this implement is totally successful when compared to his coleus harvester.

4. CONCLUSIONS

Thus, a mini tractor operated coleus digger uprooted the coleus tubers and left on the bed itself which can then be conveniently collected by farmers.

An area of 0.0640 ha in the instructional farm of KCAET was selected. Four rows of bed of dimension 30 x 0.50 x 0.30m respectively as length x breadth depth were prepared. Good quality cuttings of "Nidhi" variety were selected and planted into the beds at a depth of 5 cm. The coleus digger was developed as an attachment to a 22 hp mini tractor to uproot the coleus from raised beds and leave it in the soil itself. There were two sets of fingers, oscillating fingers and side fingers. The oscillatory motion created the necessary movement to separate the soil and tubers. The separated tubers then get deposited on the soil. The oscillatory motion was provided to the fingers by means of cam drives and connecting rods. The cam drive was connected to the output shaft of the gear box and converted its rotational motion to the oscillatory motion of the fingers. Tie rods were used between connecting rods and fingers to facilitate this power transmission.

The performance of the coleus digger was tested and evaluated in the experimental plot of the instructional farm of KCAET, Tavanur. Trials were conducted for operating speed of 1.0, 1.5 and 2.0 kmph and depth of operation of 10 and 15 cm. the number of experiments were eighteen. The observations were statistically analysed using two-way analysis of variance. The performance evaluation of the digger was carried out for time of operation and harvesting capacity for different depth of operation and operating speed. The percentage of damage and the field efficiency were also found out.

The performance of the digger for time taken (s) to dig out coleus revealed that the time taken for operation was maximum when the digger was operated at 1.0 kmph at a depth of 10 cm whereas the minimum time was observed for the operating speed of 2.0 kmph at a depth of 15 cm. The harvesting capacity of the coleus digger was also found as the same for all the treatments. The percentage of damage for the different operating speed and depth of operation was negligible.

The field capacity of the coleus digger was 0.0365 ha h^{-1}. The area covered by manual method is about6.2 x 10^{-5} ha h^{-1}. At the present wage of Rs 500 per day, the total cost of operation by manual method is about Rs 31,250 per ha. By mechanical harvesting using the mini tractor operated coleus digger, the total cost of operation was about Rs 16,400 per ha. Hence the savings over conventional method was Rs 14,850 per ha. The filed efficiency of the mini tractor operated coleus digger was calculated to be 89 per cent.

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By,

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