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Development of Mini-Tractor Operated Coleus Digger

Er. Mohamed Favazil Pulloorsangattil[1], Er. Chinnu S R[2], Er.Rachana C[3]
BE Student[1, 2, 3]
Department of Agricultural Engineering [I, 2, 3]
Kelappaji College of Agricultural Engineering and Technology, Tavanur, Kerala Agricultural University, Kerala, India

Abstract:
Solenostemonrotundifolius, commonly known as coleus/ Chinese potato/ hausa potato is an under exploited minor tuber crop grown extensively in several parts of India. In India it is known to be widely grown in most of the homestead gardens of Kerala and Tamil Nadu. Coleus is mainly confined to laterite soils of Central Kerala and Malabar, especially in the districts of Palakkad, Trissur and Malappuram constituting an area of about 200 ha and sandy coastal soils extending to Mangalore district of Karnataka (Edison, et al. 2006). Department of Economics and Statistics, Government of Kerala shows that the production of Coleus in Kerala is about 26 kilo tonnes within an area of 1370 ha. 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 as an attachment to a 22 hp mini tractor to uproot the coleus from raised beds and leave it in the soil itself in the instructional workshop, KCAET, Tavanur. 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: Coleus, Coleus Digger, Mini-Tractor, Oscillating fingers, Power take-off unit.

I.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.
- The separation of coleus after harvest was difficult.
- Non-detachment of the clumps hence it couldn't be used for beds having height more than 30 cm.
- Low ground clearance.

An ideal mechanical harvesting machine should be such that:

- It achieves a reduction in the overall production cost
- It should lead to the reduction of drudgery and tedium associated with the manual process of harvesting.
- It must achieve decrease in root losses and damage.
- The cost of the machine should be affordable to farmers and cheaper than similar imported machines.
- The materials used for fabrication should be readily available.
- The machine should be adaptable to the common varieties of root crops and changing operational parameters.

II. REVIEW OF LITERATURE

Saquib *et al*. (1986) designed and tested a vibratory digger blade for proposed use on a sweet potato harvester. Field operations caused most damage to sweet potatoes when they were dug in dry cloddy conditions. Vibration of a digger blade produced significantly smaller clods than without vibration, which imparted less damage to the sweet potato. Reduction of bulk density of soil was more in vibratory operation of the digger blade. Jadhav *et al.* (1992) designed and evaluated a simple low-cost self-propelled onion digger windrower. It was powered by a 5 hp diesel engine mounted on the frame along with the main gear box.

The digging unit consisted of sweeps fitted to the front of the frame. Baric *et al* (1994) conducted experiments on the utilization of rotary potato digger. It was found that a rotary digger could achieve good results on small plots with various row spacing.

It was simple to operate and maintain and gave good performance with less labour requirement. The optimum working speed was 4.5 km h^{-1}. Petrov *et al* (1994) developed the perspectives of mechanical sugar beet harvester. Several sugar beet harvesters from various countries were described and their technical parameters, including the engine power, number of driving wheels and operating width were compared.

Thakur *et al.* (1994) conducted performance evaluation of four different potato lifting shares, viz., rectangular, convex, triangular fork and V- scoop types under controlled soil- bin condition for the measurement of draft and field conditions by harvesting potatoes.

The draft of shares of 500 mm width when operating in silty clay loam soil at 16 % (d b) moisture content and 1.51 gm cm^{-3} dry bulk density was found maximum with rectangular share, followed by convex, triangular fork and V- scoop share. An experimental oscillatory sieve potato digger windrower was used.

The maximum recovery of potatoes at the velocity ratio of 1.38 for the different shares was evaluated. Gupta *et al.* (1995) developed an engine driven potato digger with oscillating perforated disc type blade and a soil clod separator aimed to reduce draft requirement, minimize tuber damage and human drudgery. It was powered by a two-wheel, single axle 8.6 kW tractor.

The harvesting efficiency of the machine was observed to be 100 % with tuber exposure percentage of 88 % and field capacity of about 0.19 ha h^{-1}. Agbeloyea *et al.* (1998) modified and evaluated the performance of three soil loosening devices for the purpose of pre- lift soil loosening in cassava harvesting. Loosening the soil in the root zone before lifting the tubers out of the soil is very important for efficient harvesting of cassava, in terms of both lifting force reduction and prevention of tuber damage. The three devices modified were L- tine, A- tine and a combination of a curved chisel tine working at a depth of 0.1 Â m ahead of L- tine. The results indicated that L- tines were most suitable for pre- lift soil loosening.

Azizi *et al.* (2014) designed and developed a semi- mounted one-row potato digger with rotary blade. It can be connected to a rotary potato grader. The transmission was mechanical from tractor PTO to the blade by belt and pulley, gear box, chain and sprocket. Helix containing bars were used for separating the soil. The average of damaged potatoes was 4 %. Amponsah *et al.* (2014) assessed the response of five different cassava varieties to mechanical harvesting on rigid and flat land forms. Results from field trials using a TEK mechanical cassava harvester showed that the best performance was achieved on ridged land forms which had better tuber yield and root tuber orientation. The harvester worked best on fields with minimal trash or weeds and relatively dry soils with moisture content from 12 – 16 % db. Singh (2014) developed and evaluated the performance of a digger used for onion harvesting.

Tests were conducted to check the comparative performance of developed onion digger and manual labour in the field. Digger was operated in the speed ranging from 3.76- 4.83 kmph with minimum losses at 4 kmph in first gear at a field capacity of 0.46 ha h^{-1}. An average operating depth of 7.62 cm was found to be optimum for minimum damage to the onion bulbs. The digger efficiency was found to be 89.8 %. It was found that there 58% savings in labour and 49% in cost.

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. 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.

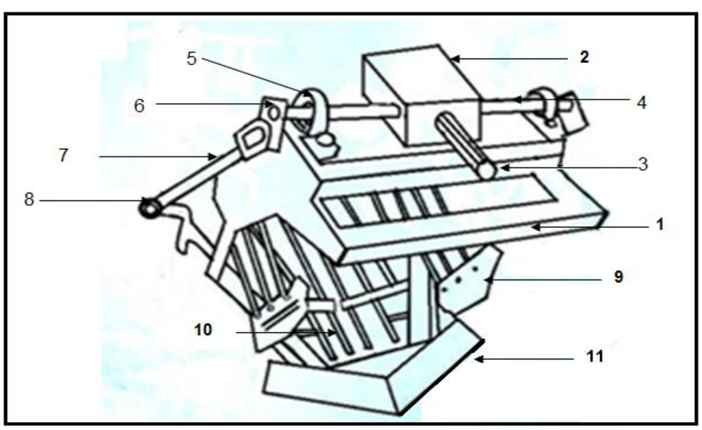
III.MATERIALS AND METHODS

Objective of study is to develop a Mini-tractor driven Coleus digger shown in Figure 1to harvest coleus tubers shown in Figure 2 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.

Figure .1. Mini-tractor driven coleus digger

Figure.2. Coleus tubers

1. Development of Mini-tractor operated Coleus Digger: A TNAU model of ginger harvester operated by a power tiller was studied in detail. Its design was modified to make it suitable to uproot coleus tubers, schematic diagram is shown in Figure 3. Thus, a mini tractor operated coleus digger was developed. The digger was operated by a 22 hp mini tractor by obtaining the drive from the tractor p.t.o through a gear box having gear ratio of 1.6:1. The digger consisted of a frame, share, finger assembly, cam drive and connecting rods, a gear box and a drive unit. The width of operation was maintained at 50 cm. The oscillatory movement of the finger assembly was found to be advantageous for various reasons such as easy forward movement, less scattering of uprooted tubers and less damage to the tubers. The drive from the tractor p.t.o was transferred to the gear box through a universal coupling. The gear box was welded on to the main frame with the two output shafts directed sideways. These were then connected to a pair of cam drives which provided the oscillatory movement. The movement was transferred to the finger assembly through connecting rods by means of the tie rods. A pair of side fingers welded to the land sides were placed on either side to prevent the scattering of coleus outward. Side view of the Coleus digger is shown in Figure 4



1. Frame
2. Gear box
3. Cam drive
4. Tie rod
5. Land side
6. Oscillating fingers
7. Share
8. Plumber block
9. P.T.O. input shaft
10. Connecting rod
11. Output shaft

Figure .3.Schematic of mini tractor operated coleus digger

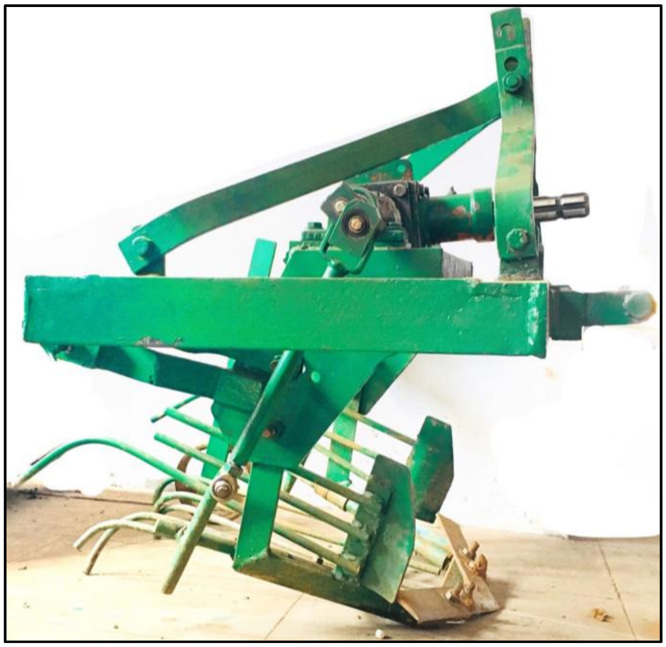


Figure.4. Side view of Mini Tractor operated Coleus diggeR

1.1 Prime mover

The prime mover was selected on the basis of its capacity to meet the power requirement for breaking the soil and uprooting the tuber. The TNAU ginger harvester used a 12 hp power tiller to harvest ginger. Also, the total weight of the implement was around 80 kilograms. Taking these into consideration, VST Mitsubishi VT 224-1D tractor of 22 hp was found suitable and was selected as the prime mover.

1.2 Frame

Frame accommodated all the attachments and accessories of the digger. It was made up of mild steel of dimensions 1.05 m x 0.50 m x 0.065 m respectively, as length x breadth x height. The frame held the share and the fingers and was bolted to the three-point hitch assembly of the tractor.

1.3 Share

The V-shaped share had an including angle of 135^0 with two arms of 25 cm each. It was made of mild steel. It was inclined at an angle of 33^0 with the horizontal surface to facilitate penetration. The penetration into the soil was achieved by the draft of the tractor and uplifted the soil along with the tubers. The share rested on a flat metal piece and was fastened by nuts and bolts.

1.4 Finger assembly

There were two parts of the assembly; the oscillating fingers and the land sides. The two sets of oscillating fingers, 3 fingers each, constituted the moving part of the digger. The oscillation was obtained from the drive unit. The fingers were made from MS rods of 0.01 m diameter and length 0.40 m. It was bent at the rear end to drop the soil lump on to the bed without much scattering. The fingers were drilled through square rods and welded in place.

The land sides were aligned at both sides of the share, orthogonal to the ground. It bore the side thrust imparted by the soil and prevented the scattering of soil side ward. They were 3 in number on each side. Two fingers were of length 0.30 m and lowest one was 0.40 m. They were attached at the front end to a flat metal sheet which is slightly bent outwards.

1.5 Cam drive and connecting rod

The cam drives connected to the output shafts of the gear box together with the connecting rods produced the oscillatory motion. The rotary motion of the gear shaft was converted to the oscillatory motion of the connecting rods by providing an eccentricity of 0.3m. The rods transferred this motion to the oscillating fingers connected to them.

1.6 Gear box

The Figure 5 shows gear box which was welded on the main frame with the input shaft connected to the tractor power take off and the two output shafts connected sideways to the cam drive. The gear box was necessary to provide the optimum rpm required for the operation without causing much scattering and damage. It had a reduction ratio of 1.6:1 and provided an rpm of about 340 to the output shafts. The calculation of the gear ratio of the gear box is illustrated below.

Determination of speed of output shaft

Specifications of gear box,

No of teeth on pinion gear = 16

No of teeth on crown gear = 10

Speed reduction ratio of gear box = 1.6: 1

Speed of input shaft (PTO), rpm = 540

Therefore, speed of output shaft, rpm

$$= \frac{540}{1.6} = 337.5$$

Rounded value = 340 rpm

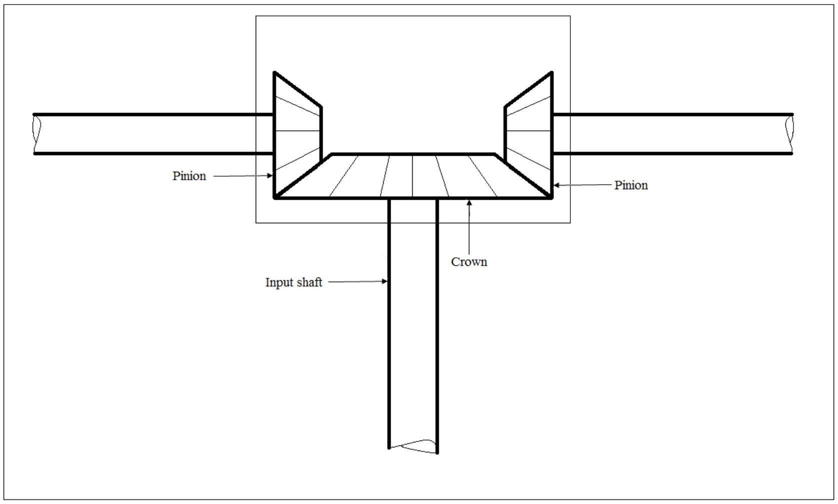


Figure.5.Schematic diagram of Gear box

1.7 Drive unit

The necessary power for the operation and consisted of the p.t.o shaft of the mini tractor and the universal coupling. The p.t.o provided two rpm, viz., 1000 and 540. The coupling was connected to the input shaft of the gear box of the implement. It also facilitated the easy movement during the lifting and lowering of the implement. The power transmission from the tractor p.t.o to the oscillatory fingers is shown in Figure 6.

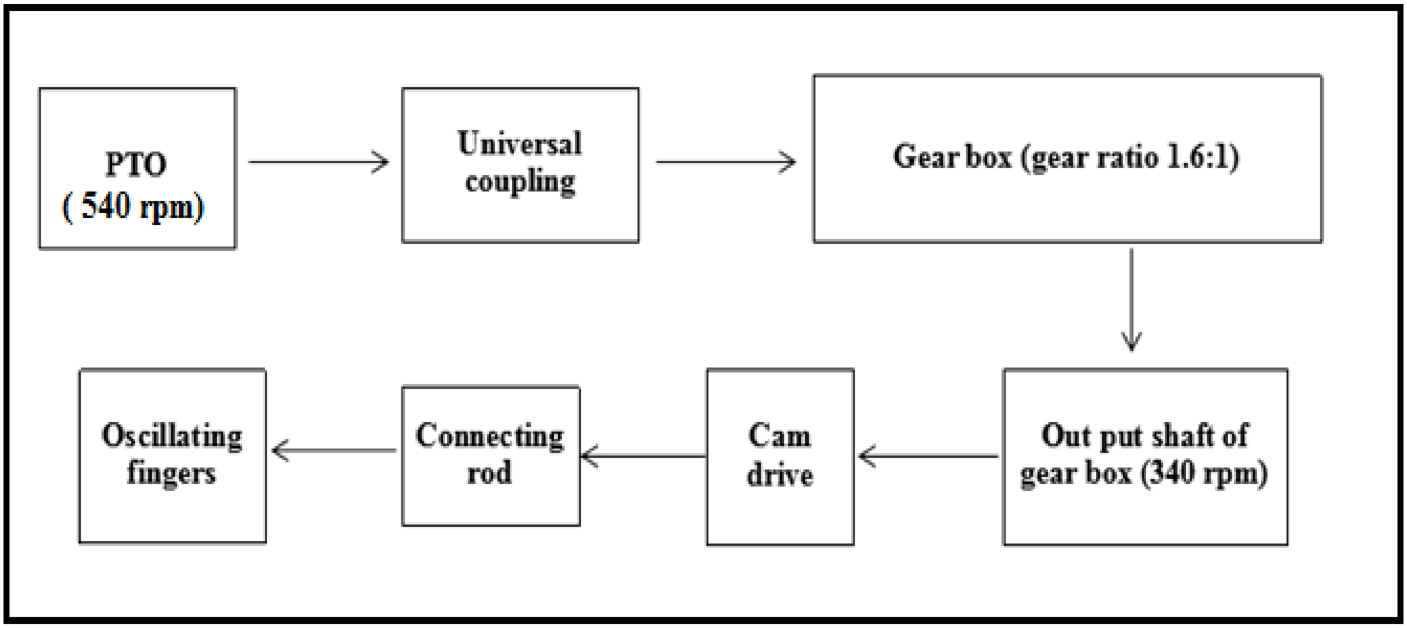


Figure.6. Power train of coleus digger

2. WORKING:

The tractor PTO provided 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 anduprooted 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. The Figure 7 below shows the 2D view of the Mini-tractor operated Coleus digger drawn in CAD. Specifications of Coleus digger is given in Table I.

Table .1. Specifications of the Coleus Digger

COMPONENTS	SPECIFICATIONS
Main Frame	Dimension - 1.05 m x 0.50 m x 0.065 m
Weight of implement	81.05 kg
Share	Tilt angle- 33°, Included angle between the 2 arms (25cm each)- 135°, cutting width- 50 cm
Finger assembly	Diameter- 10 mm, Oscillating fingers: Length- 40 cm, 2 sets (3 fingers each), land sides: 2 sets (3 fingers each)
Cam drive	2 No., Eccentricity- 30 mm
Connecting rod	2 No., length- 40 cm
Gear box	Gear ratio- 1.6: 1, 2 pinions and 1 crown

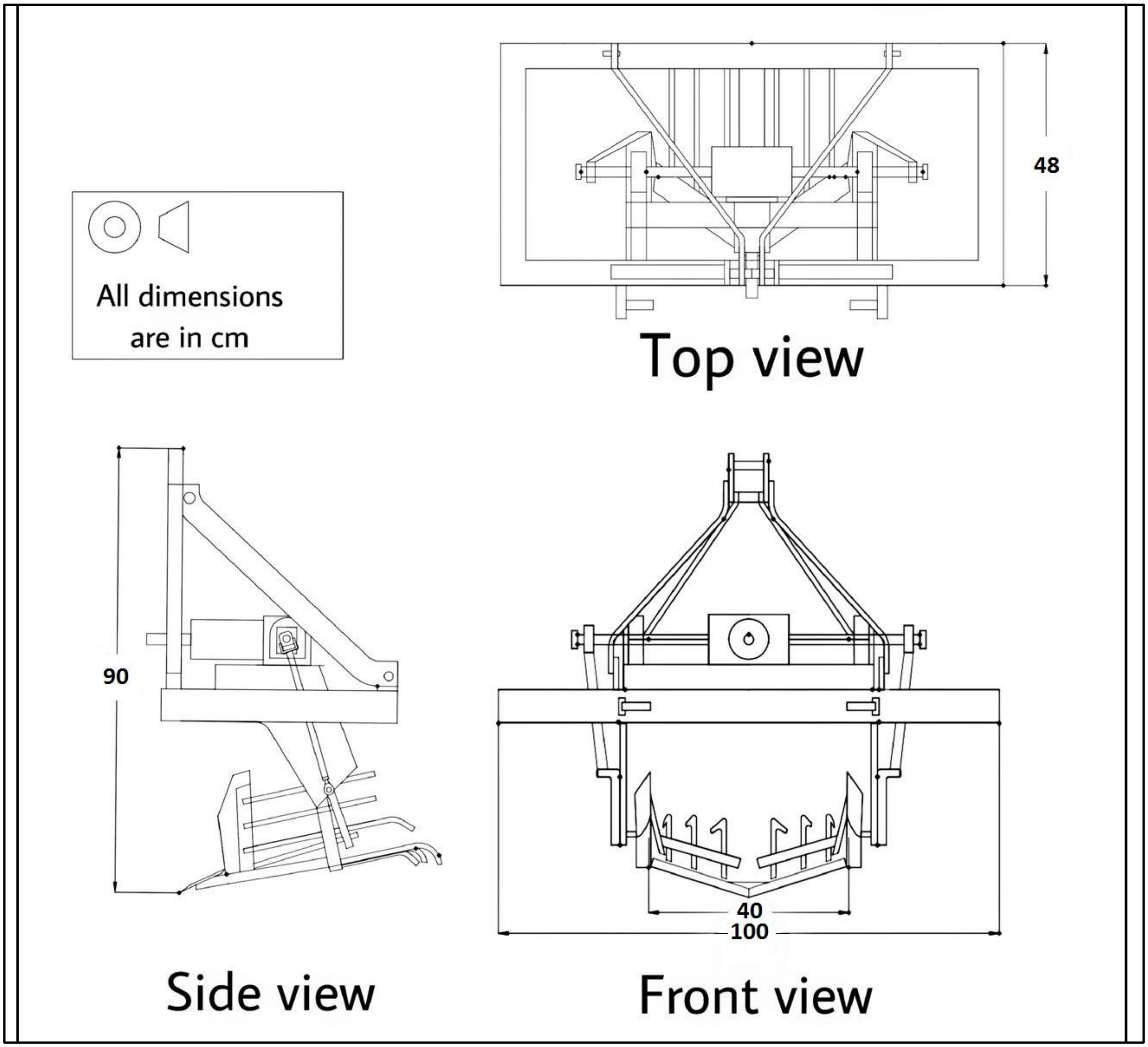


Figure.7. Mini-tractor operated Coleus digger (CAD)

IV. RESULTS AND DISCUSSION

The Coleus digger was developed 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.

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 isRs 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

$:\left(\frac{(costofminitractor + salvagevalue)}{2}\right) x interestrate$

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

(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

II. (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

III. 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 investmentcost): 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

$: \left(\frac{initialcost + salvagevalue}{2}\right)$ x Interest rate

$= \frac{45000 + 4500}{2} \text{x } 0.07 \qquad = 1732.5$

(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-$\frac{fixedcostperyear}{working\ hoursperyear}$

$= \frac{7132.5}{200} = 36$

II. Variable cost

(I) Repair and maintenance per hour, Rs:$\frac{45000}{200}$x0.05
= 11.25

III. Total cost per hour, Rs : Fixed cost + variable cost
: 36 + 11.25
= 47.25

Total cost per hectare,

Rs:$\frac{totalcostper\ hourforcoleus\ uprooter + minitractor}{fieldcapacity}: \frac{47.25+551.25}{0.0365}$
= 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.

V. 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. *Solenostemon rotundifolius,* commonly called as coleus / Chinese potato/ hausa potato is a minor tuber crop widely cultivated in the homestead gardens of Kerala and Tamil Nadu. In Kerala, there is an extensive cultivation of coleus in the districts of Palakkad, Thrissur and Malappuram. It grows well in the regions with well drained medium fertile soil. In Kerala, the ideal cultivation is from July to October every year. The farmers grow the tubers on raised beds in fields. Nursery is generally raised one month before planting. This is followed by planting the cuttings of length 10- 15 cm on beds of spacing 30 x 15 cm. Traditionally coleus is harvested manually when haulms dry up. The tools used are hoes and spades. This is time consuming and labourious and require proper handling to reduce damage of coleus. Hence farmers prefer for mechanical harvesting to save time and cost. Several models of mechanical coleus harvesters were developed in KAU. However, the results were not satisfactory because of the higher damage of tuber caused by the excessive vibration. Thus, a mini tractor operated coleus digger was developed that uprooted the coleus tubers and left on the bed itself which can then be conveniently collected by farmers. 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. It consisted of a frame, share, finger assembly, cam drive and connecting rods, gear box and a drive unit. The width of operation was maintained at 50 cm. Oscillatory motion was provided to the finger assembly which was found advantageous because it caused less scattering of the tubers. All the attachments and accessories were accommodated by the frame of dimension 1.05 x 0.50 x 0.065 m. The V-shaped share made contact with the soil first and penetrated into the soil to uplift the soil along with tubers. 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.

Future works

The main concern regarding the development of the mini tractor operated coleus digger is the actual bed size at which the farmers grow coleus in fields. The bed width is almost 1.0 m with a bed height of 50 cm. The mini tractor operated coleus digger cannot be operated in such fields. However, with respect to percentage of damage and easiness of operation, the coleus digger operated with a tractor having greater than 35 hp is a better option.

VI. REFERENCES

[1]. Al-Jubouri, K.A.J. and McNulty, P.B. 1984.Potato digging using orbital vibration.J. Agric. Engng. Res. 29:73-82.

[2]. Agbetoyea, L.A.S., Kilgourb, J. and Dysonb, J., 1998. Performance evaluation of three pre- lift soil loosening devices for cassava root harvesting. Soil Tillage and Results.48(4): 297-302.

[3]. Amponsah, S.K., Bobobee, E.Y.H., Agyare, W.A., Okyere, J.B., Aveyire, J., King, S.R. and Sarkodie- Addo, J. 2014. Mechanical cassava harvesting as influenced by seed bed preparation and cassava variety.Applied Engineering in Agriculture. 30(3): 391-403.

[4]. Azizi, P., Dehkordi, Sakenian, N. and Farhadi, R. 2014. Design, construction and evaluation of potato digger with rotary blade. CertetăriAgronomiceînMoldov.,Vol. XLVII, 3:159.

[5]. Anonymous, 2016. Package of Practices, Kerala Agricultural University, Thrissur,

[6]. Baraic, J., Stefanele, E., and Lulcac, P. 1994.Utilization of rotary potato digger. Proceedings of 22 International meeting on Agricultural Engineering conference, Croatia,Europe.

[7]. Chamen, W.C.T., Cope, R.E. and Patterson, D.E. 1979. Development and performance of a high output rotary digger.J. Agric. Engng. Res. 24: 301-318.

[8]. Edison, S., M. Unnikrishnan,,Vimala, B., Pillai, Santha, V., Sheela, M.N., Sreekumari, M.T., and Abraham, K. 2006. Biodiversity of Tropical Tuber Crops in India. Central TuberCrop Research Institute, Thiruvananthapuram. pp:11-12.

[9]. Gupta, C.P. and Wolf, D. 1995. Engine driven potato digger with oscillating blade for small farm use.Submitted to The Office of the Science Advisor, U.S. Agency for International Development.

[10]. Hanna, M. 2001.Estimating Field Capacity of Field Machines.Cooperative Extension Service, Iowa State University of Science and Technology, PM 696, pp 14.

[11]. Jadhav, R.V and Gharte. 1992. Design, development, and performance evaluation of an onion digger windrower. AMA, 26 (2).35-38.

[12]. Obigol, E.U. 1986. Single row Model-2 cassava harvester. AMA.22 (2):63-66.

[13]. Otuwose, A.E., Jayeola, A.A., Bashir, A.A and Blessing, J.M. 2014. Exo- morphology of vegetative parts support the combination of Solenostemonrotundifolius (Poir) J.K.Morton with PlectranthusesculentusN.E.Br. Natal (Lamiaceae) with insight into infraspecific variability.AAB Bioflux6 (1): 16-17.

[14]. Perdok, U.D. and Kouwenhoven, J.K. 1994. Soil- tool interaction and field performance of implements.Soil Tillage Research.30 (2): 283-326.

[15]. Petrov, G.D., Karienko, A.V. and Nanaeko, A.K. 1994. Perspective ofmechanical sugar beet harvesting. Sakharraya Svelta, Russia, no.9. pp:5-9.

[16]. Sinclair, D.F. and Williams, J. 1979. Components of variance involved in estimating soil water content change using a neutron moisture meter. Australian J. Soil Res. 17(2): 237-247.

[17]. Schmugge, T.J., Jackson, T.J. and McKim, H.L. 1980. Survey of methods for soil moisture determination.Wiley Online Library.

[18]. Saqib, G.S. and Wright, M.E. 1986. Vibratory diggers for harvesting seed potatoes in cloddy soils. J. Agric. Engng. Res. 34:53-61.

[19].Singh, Mahesh Chand. 2014. Development and performance evaluation of a digger for harvesting onion (Allium cepaL.). Internat. J. Agric. Engg., 7(2): 391-394.

[20]. Thakur, T.C. and Tiwari, P.S. 1994.Soil bin investigation and field performance evaluation of lifting shaves used on potato harvester. J. AgricEngg. 31(9). pp: 19-21.

[21]. Thompson, R.B., Gallardo M., Valdez L.C. and Fernandez, M.D. 2007. Determination of lower limit for irrigation management using in situ assessments of apparent crop water uptake made with volumetric soil water content sensors. Agricultural Water Management.92:13-28

[22]. Vaz, C. M. P., Bassoi, L. H. and Hopmans, J. W., 2001.Contribution of Water content and Bulk density to field Penetration Resistance as measured by a Combined Cone penetrometer – TDR Probe.Soil and Tillage Research, 60: 35-42.

[23]. Younus, A., 2014. Modification and testing of a coleus harvester.Unpublished Mtech Thesis.Kelappaji College of Agricultural Engineering and Technology, Tavanur.

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