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Dnyanesh Vhatkar

M.Tech, Farm Machinery and
Power Engineering, College of
Agricultural Engineering and
Technology, Dapoli, Maharashtra,
India

Dr. AA Deogirikar

Assistant Professor, Department of
Agricultural Engineering, College
of Agriculture, Dapoli,
Maharashtra, India

Dr. KG Dhande

Professor (CAS), Department of
FMPE, Dapoli, Maharashtra, India

Dr. AG Mohod

Professor and Head, Department
of REE, CAET, Dapoli,
Maharashtra, India

Dr. PS Gudadhre

Assistant Horticulturist, AICRP
on tuber crop, Wakavali,
Maharashtra, India

Performance evaluation of “Ridger type” lesser yam digger

Dnyanesh Vhatkar, AA Deogirikar, KG Dhande, AG Mohod and PS Gudadhre

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Abstract

Dioscorea esculenta, commonly known as lesser yam. It is cultivated in Kerala, Goa, Konkan region of Maharashtra in India. Usually, the matured rhizomes are dug manually using hand tools or Pickaxe. Manual harvesting of lesser yam very laborious that needs approximately 300 - 350 man-h/ha including minimum resting period. But power tillers are used by the farmers for the puddling or land preparation. Considering this, it was felt necessary to develop a power tiller operated lesser yam digger suitable for small land holdings. Hence, the study entitled “Development and performance evaluation of power tiller operated lesser yam digger” was undertaken. Based on design considerations it was decided to develop ridger type equipment. Filler trials of the ridger type blade were found satisfactory but required to have some modifications to make it suitable for the current cultivation practices. operating parameters decided were the rake angle of the blade (10°, 15°, 20°, 25° and 30°) and the forward speed of the implement 0.5, 0.75, 1, 1.25, 1.5 km/h as per previous studies and depth of operation was considered 400 mm. However, during experimentation, it was observed that the digger was working properly till 260 mm depth only. The results of performance of lesser yam digger showed that, at forward speed 1 km/h and rake angle 20°, the dug tubers capacity (%), damaged tubers percentage (%), undug tubers capacity (%), damaged undug tubers percentage (kg/ha), digging efficiency (%) and field efficiency (%) were 8520 kg/ha, 22%, 2400 kg/ha, 38%, 78%, 85% respectively. The total development cost for digger was ₹ 4040/- and operating cost was found to be ₹ 7270 /ha respectively. The cost of manually digging was observed to ₹ 12000/ha. Therefore, it was found that the lesser yam harvesting cost with developed root crop digger was 39.41% less than that of manual harvesting method. The net saving in turmeric harvesting with root crop digger was ₹ 4730/ha.

Keywords: Root crop digger, yam harvester/digger

1. Introduction

Dioscorea esculenta, commonly known as lesser yam. It is grown for their edible tubers. It is cultivated in Kerala, Goa, Konkan region of Maharashtra India. In Malayalam, it is known as nana kizhangu or nheruvalli kizhangu or Cheru Kizhangu". In Goa it is called Kaate Kanaga (काटे कणगा). In usual practice, the rhizomes are dug manually using hand tools or Pickaxe. About 10% to 40% of the yam tubers get damaged during harvesting period, piercing from the roots of trees and due to poor handling of tubers (Otoo *et al.* 2013) [22]. Even in mechanical harvesting, about 19% tuber damage is observed and reported using the tractor mounted yam harvester fitted with collection unit (Opara, 2003, Itodo and Daudu, 2007). Hence, there is a need of mechanical harvesting method to reduce the tuber damage during harvesting and handling (Otoo *et al.*, 2013) [22]. The manual cost of turmeric harvesting shares 30 to 40% of total cost of production (Khambalkar, *et al.* 2019) [7]. (Khadke *et al.*, 2015 and Ramtahal, 1971) [14]. Rhizome damage, about 10 to 15%, is one of the biggest problems in manual harvesting (Munde *et al.*, 2010, Madan, 2008) [18]. Shortage of the labours during the peak harvesting season is major problem in manual harvesting method (Khambalkar, *et al.* 2019) [7].

In Konkan region, mostly Paddy is cultivated as rain fed crop. Vegetable crops are not cultivated because of the lack of irrigation facilities and nuisance of wild animals. In Konkan region due to small land holdings, lesser yam is manually cultivated in Raigad, Sindhudurg, Khed etc.

Corresponding Author:

Dnyanesh Vhatkar

M.Tech, Farm Machinery and
Power Engineering, College of
Agricultural Engineering and
Technology, Dapoli, Maharashtra,
India

The previous studies on the root crop digging and observations recorded for the lesser yam harvesting at CRS, Wakavali indicated that manual harvesting of root crops is very drudgerous work. Manual harvesting of lesser yam needs approximately 300-350 man-h/ha including minimum rest period. It is also observed that lesser yam is cultivated on the small land holdings in the Konkan region. that requires great amount of labour. It indicates that the root crop cultivation is increasing in this region due to suitable climate and soil types. If a root crop digger or harvester suitable for these crops is available, the area under cultivation of these crops may increase at exponential rate. Considering this fact, it was felt necessary to develop a power tiller operated lesser yam digger suitable for small land holdings.

2. Materials and methods

2.1 Design and development of power tiller operated lesser yam digger

The digger was planned to be developed for digging or exposing the lesser yam tubers from the field and dropping it at rear of digger in field those are to be picked manually. It was decided to develop ridger type digging blade using vertical holding beam, main frame with the wheel to support it during its forward motion through field.

2.1.1 Theoretical determination of draft on digging blade

The experiment was conducted to analyze the forces acting on the tillage tool and the soil to develop an expression for the total draft needed to overcome the various soil reactions and concluded that soil-metal friction, shear failure, acceleration force for each block of soil, and cutting resistance act on the tillage tool as it moves through the soil (Soehne 1952)^[23]. The expression given by Soehne was used to access the draft calculations (Ibrahim *et al.*, 2011). Fig. 2.1 and 2.2 shows soil and tool reaction forces. The specific draft force (D^*) is defined as:

$$D^* = \frac{W}{z} = \frac{C A_1 + B}{z (\sin \beta + \mu \cos \beta)}$$

Following assumptions were made for the calculation and the values calculated for theoretical draft are given below:

$$D^* = \frac{W}{z} + \frac{C A_1 + B}{z (\sin \beta + \mu \cos \beta)} = 1707.63 \text{ N}$$

$$W = \text{Soil weight} = \gamma b d^* \left[L_0 + \frac{L_1 + L_2}{2} \right] = 232.49 \text{ kg.}$$

$$z = 12.4$$

$$C = 500 \text{ kg/m}^2 = 4903.35 \text{ Pa}$$

$$A_1 = \text{Area of forward shear failure surface, m}^2. = \frac{b d}{\sin \beta} = 0.28 \text{ m}^2$$

$$B = \text{Acceleration force.} = \frac{\gamma}{g} b d v_o^2 \frac{\sin \delta}{\sin(\delta + \beta)} = 4.88$$

$$\beta = \text{Angle of the forward failure surface, rad} = (90^\circ - \phi)/2 = 33.28^\circ$$

$$\delta = 25^\circ.$$

$$\mu = \text{Coefficient of internal soil friction} = \tan \phi = 7.53$$

$$\mu' = 0.3.$$

$$\phi = 23.43^\circ.$$

$$b = 0.60 \text{ m.}$$

$$d = 0.40 \text{ m.}$$

$$d^* = d \{ [\sin(\delta + \beta)] / \sin \beta \}, \text{ m. } 0.62 \text{ m}$$

$$\gamma: 1327 \text{ kg/m}^3.$$

$$L_0 = 0.40 \text{ m.}$$

$$L_1 = d \{ [\cos(\delta + \beta)] / \sin \beta \}, \text{ m. } 0.38 \text{ m}$$

$$L_2 = d^* \tan \delta, \text{ m. } 0.28$$

$$V_o = 0.55 \text{ m/s.}$$

$$g = 9.81 \text{ m/s.}$$

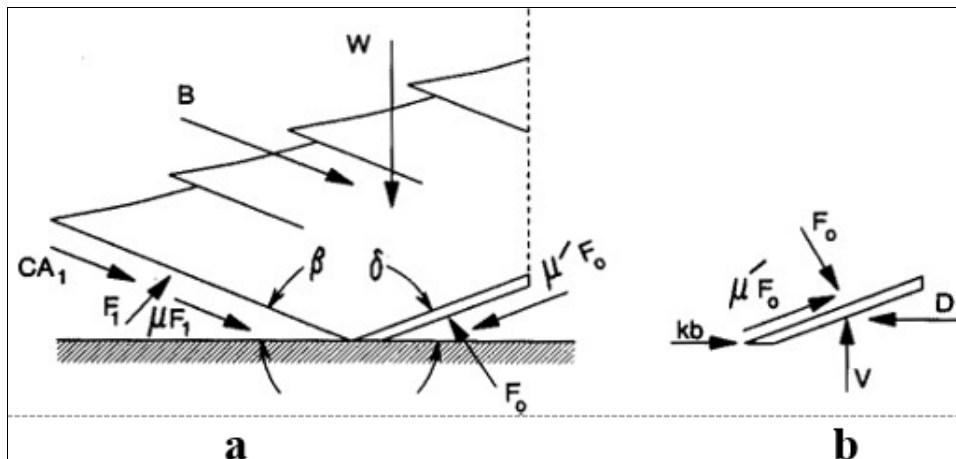


Fig 1: Soil and tool reaction forces (free body diagram of a segment of soil as it reacts to the advancing tool)

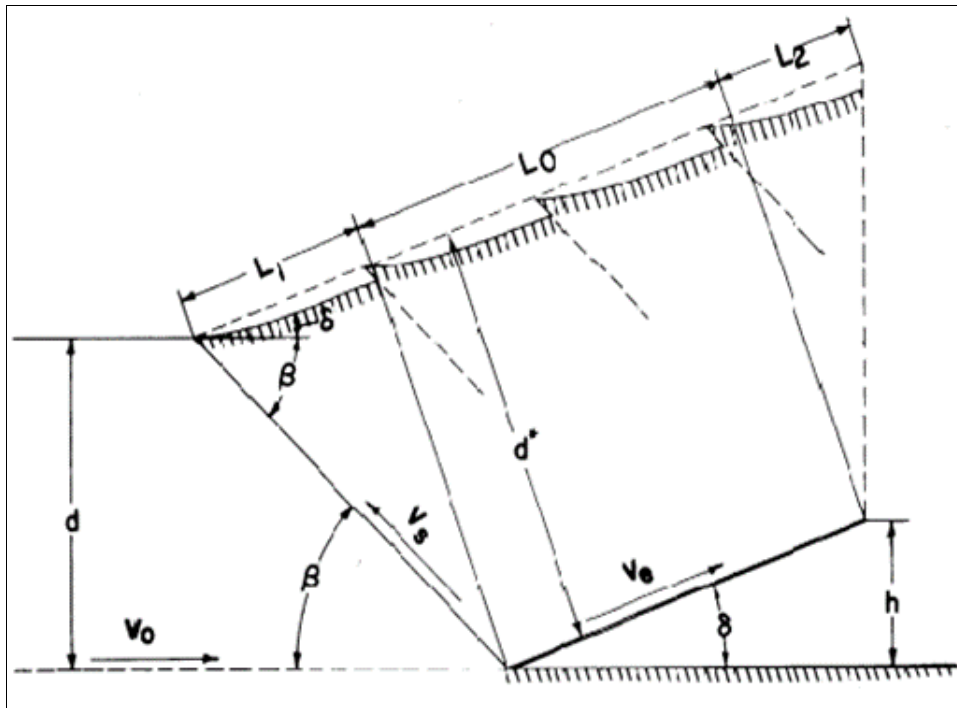


Fig 2: Geometrical relations between velocities and lengths for a segment of soil reacting to an inclined tillage tool (Soehne *et al.*, 1956) ^[23]

2.1.2 Design of digging blade and beam holder

The shape of the blade was designed with the intention that it should quickly transfer or move the soil and uprooted tubers to its side to avoid clogging or jamming this material over the blade. The width of blade was decided based on width of raised bed on which lesser yam grows in single row. The blade was designed with its thickness considering load acting on it according to the theoretical calculations. It was necessary to design and manufacture a connection which holds the digging blade fitted on the rear side of main frame using two nut and bolts. The calculation of bending moment for the beam holder is

followed by the calculation methodology used by Ibrahim (2011).

Section A – A is subjected to: (Fig 2.3)

$$(M_b)_h = F_h L$$

Where

M_b = Bending moment applied on the blade, N.mm.

F_h = horizontal load = $D^* = 1707.63$ N (theoretical calculation).

L = Blade length from the blade edge to the supporting point = 400 mm

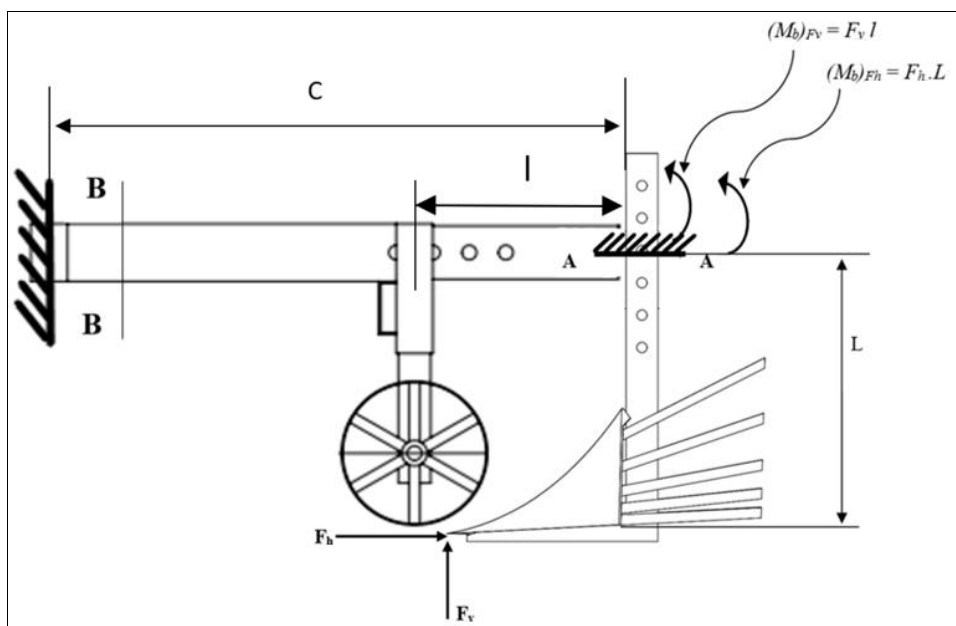


Fig 3: Forces acting on the digging blade

$$\text{Bending stress } (\sigma_b) = \frac{M_b y}{I}$$

Where

$$I = \text{Bending moment of inertia} = \frac{1}{12} (b) \cdot (t)^3$$

t = Beam width, mm = 60 mm

b = Beam thickness, mm = 6 mm

$$y = \frac{t}{2}, \text{ mm}$$

$$\text{Bending stress } (\sigma_b)_h = \frac{F_h L \times \frac{60}{2}}{\frac{1}{12} (6)(60)^3} = 0.474 \text{ N/mm}^2 \text{ (MPa)}$$

2. Bending stress due to vertical load (F_v): $(M_b)_v = F_v \times l$
 $F_v = F_h \tan 20^\circ = 1707.83 \times \tan 20^\circ = 621.52 \text{ N}$

$$(\sigma_b)_v = \frac{M_b y}{I} = \frac{621.52 \times \frac{60}{2}}{\frac{1}{12} (6)(60)^3} = 0.17 \text{ N/mm}^2 \text{ (MPa)}$$

$$(\sigma_b)_{\text{total}} = (\sigma_b)_h + (\sigma_b)_v = 0.474 + 0.172 = 0.646 \cong 1 \text{ N/mm}^2$$

3. Compression stress due to the vertical load (F_v):

$$\sigma_c = \frac{F_v}{A} = \frac{621.52}{6 \times 60} = 1.72 \cong 2 \text{ N/mm}^2$$

It can be neglected compared to the bending stress applied on the beam section. Max stress applied on beam section is normal stress with value of 2 N/mm^2 (approx).

Beam material for safety factor more than 2, where $S_y \geq 440 \text{ N/mm}^2$ should be used.

Tensile strength (ultimate) of mild steel is 440 N/mm^2 (MPa) which is far greater than calculated bending stress.

∴ The mild steel can be used for fabrication of beam support.

Section B – B is subjected to: (Fig 2.3)

1. Bending moment

$$M_b = M_t + F_v C = (F_h L + F_v l) + F_v C$$

$$M_b = 1707.83 \times 400 + 621.52 \times 250 + 621.52 \times 1200 = 1584336 \text{ N.mm}$$

$$(\sigma_b) = \frac{M_b y}{I} = \frac{1584336 \times \frac{80}{2}}{\frac{1}{12} (80)(80)^3} = 18.56 \text{ N/mm}^2 \text{ (MPa)}$$

2. Tensile load

$$\sigma_t = \frac{F_h}{A} = \frac{1707.83}{80 \times 80} = 0.26 \cong 1 \text{ N/mm}^2$$

$$(\sigma)_{\text{total}} = (\sigma_b) + (\sigma_t) = 18.56 + 1 = 19.56 \cong 20 \text{ N/mm}^2$$

$$S_{\text{ultimate}} = \frac{(\sigma)_{\text{total}} \times \text{Factor of safety}}{0.7} = 57.14 \text{ N/mm}^2$$

So that same material can be used in main frame design.

Radius of curvature: The radius of curvature of the implement was designed as per the calculations used for determining the radius of curvature for MB plough as suggested by Shrestha *et al.* 2001.

The radius of curvature is given by,

$$R_c = \frac{b - r'}{\psi} = \frac{0.60 - 0.49}{0.34} = 0.32 \text{ m} = 320 \text{ mm}$$

Where

R_c = radius of curvature (m).

b = width of plough (m).

ψ = rake angle (radians).

$$r' = b - v \tan \lambda = 0.60 - 0.55 \times 0.54 \times \tan 20^\circ = 0.49$$

v = forward speed of plough (m/s).

t = the time period in seconds after the soil furit comes in contact with the plough

λ = share angle of the plough (degrees).

So, the radius of curvature of the ridger type blade was 320 mm.

2.1.3 Development of lesser yam digger

a. Digging blade

The ridger blade of the digger was fabricated using two curved shaped MS triangular sheets having sides of $300 \times 300 \times 350 \text{ mm}$ and thickness 3 mm that was welded on bent L angle ($37.5 \times 37.5 \times 3 \text{ mm}$) and MS flat beam support ($50 \times 6 \times 600 \text{ mm}$). Beam support was connected to the main frame with 2 nut and bolts. The ridger type blade was welded on the beam support such that the rake angle of blade for digging should meet 20 degrees to the horizontal ground and the bend of blade should attach to beam support at an angle 35 degrees to the horizontal. The radius of curvature was 320 mm.

b. Main frame

The main frame consists of hitching attachment ($150 \times 80 \times 6 \text{ mm}$) welded with the T shaped frame ($(80 \times 80 \times 3) \times 500 \text{ mm}$ square pipe and $(80 \times 80 \times 3) \times 800 \text{ mm}$ square pipe). The main frame had one telescopic square pipe with the holding attachment on which the digging blade was fitted using nut and bolts. The horizontal section of T shaped frame had 2 support wheels which distributes the dynamic suction load of the digging throughout the frame. The dynamic load stayed constant with the depth and width of cut because of the support wheels restrict the digger from sinking into the soil.

c. Ground wheels for lesser yam digger

The ground wheels of lesser yam digger were fabricated and are shown in Fig. 3.10 using MS flat ($50 \times 3 \text{ mm}$). The base diameter of wheel was 580 mm so that during digging operation, the wheels should run through the gaps between two raised beds and due to the angle lugs this cage wheels provides more traction compared to pneumatic wheels. The inside spacing between the wheels when mounted on the power tiller was 600 mm which was suitable for operation of lesser yam digging. The developed digging blade, main frame and grounds are attached on the power tiller.

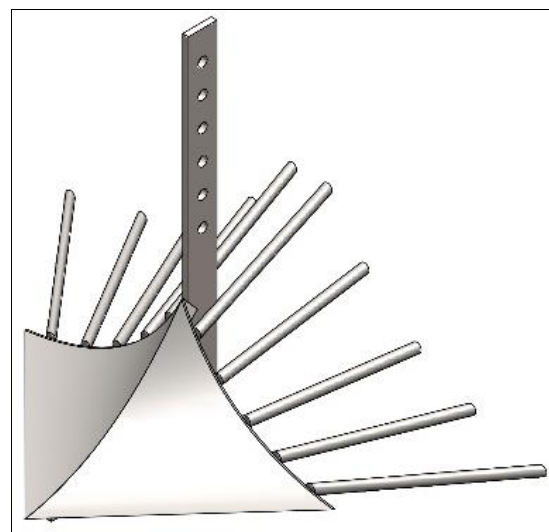


Fig 4: Isometric view of digging blade

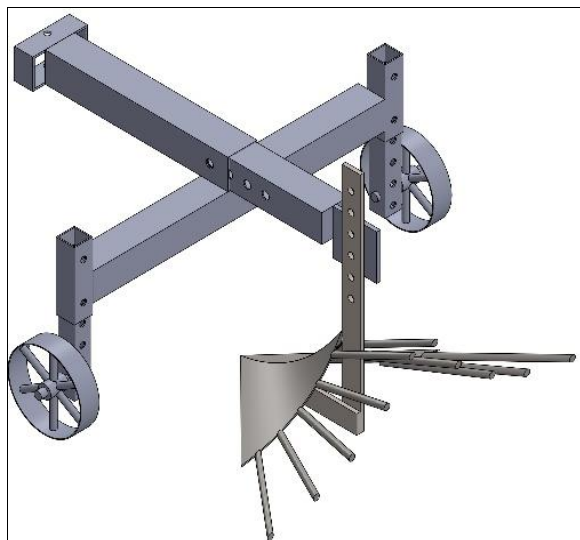


Fig 5: Isometric view of developed lesser yam digger

3. Results and Discussion

The performance of the developed power tiller operated lesser yam digger was evaluated at different forward speeds with the variable rake angles and fixed depth of digging equipment. This chapter presents the results of trials under the following broad headings.

3.1 Performance evaluation of developed lesser yam digger

The effect of operational parameters i.e. forward speed and rake angle on the performance lesser yam digger for dug tubers capacity (kg/ha), damaged tubers percentage (%), undug tubers capacity (kg/ha), damaged undug tubers percentage (%), digging efficiency (%) and field efficiency (%) was studied.

3.1.1 Dug tubers capacity

It is the total quantity (kg) of tubers dug by the lesser yam digger, later converted to kg/ha. Dug tubers capacity decreased with increase or decrease of forward speed and rake angle. The dug tubers capacity observed minimum (7048 kg/ha) at forward speed 0.5 km/h and rake angle 30° also it was seen minimum (7324 kg/ha) at forward speed 1.5 km/h and rake angle 30°. Similar kind of results were seen at forward speed 0.5 km/h and rake angle 10° and also at forward speed 1.5 km/h and rake angle 10° the dug tubers capacity was minimum (7856 kg/ha and 7432 kg/ha respectively). It might be happened because increase in rake angle increases the soil load on blade causes poor penetration and decrease in rake angle causes less desired depth. Deshvena *et al.* (2019), (Harrison, 1982) observed similar results.

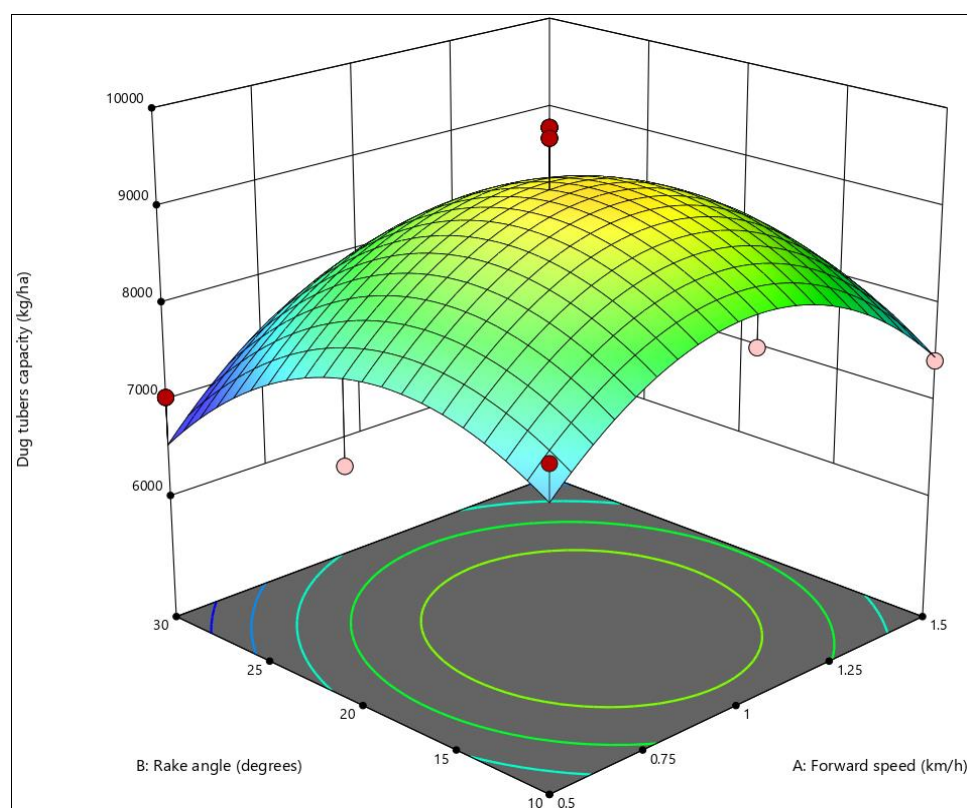


Fig 6: Effect of rake angle and forward speed on dug tubers capacity

3.1.2 Damaged tubers percentage

The effect of forward speed and rake angle were studied on damaged tubers percentage and are presented in Fig. 3.2. It was observed that the damaged tubers percentage increases with increase in forward speed, the maximum (25%) tubers were damaged at forward speed 1.5 km/h. It might be happened due to the less desired depth acquired while operating power tiller, also due to more speed blade did not reach at required depth caused

cutting and damage of tubers. Narender *et al.*, (2016) ^[20] observed that the number of tuber damage and digging efficiency is affected by forward speed. The minimum (23%) tuber damage observed at forward speed 0.5 km/h. It might be due to steady and low speed digging operation which causes proper scoring of soil and more reach depth of digging. The continuous circular shape of the blade has direct interaction with the digging of the soil.

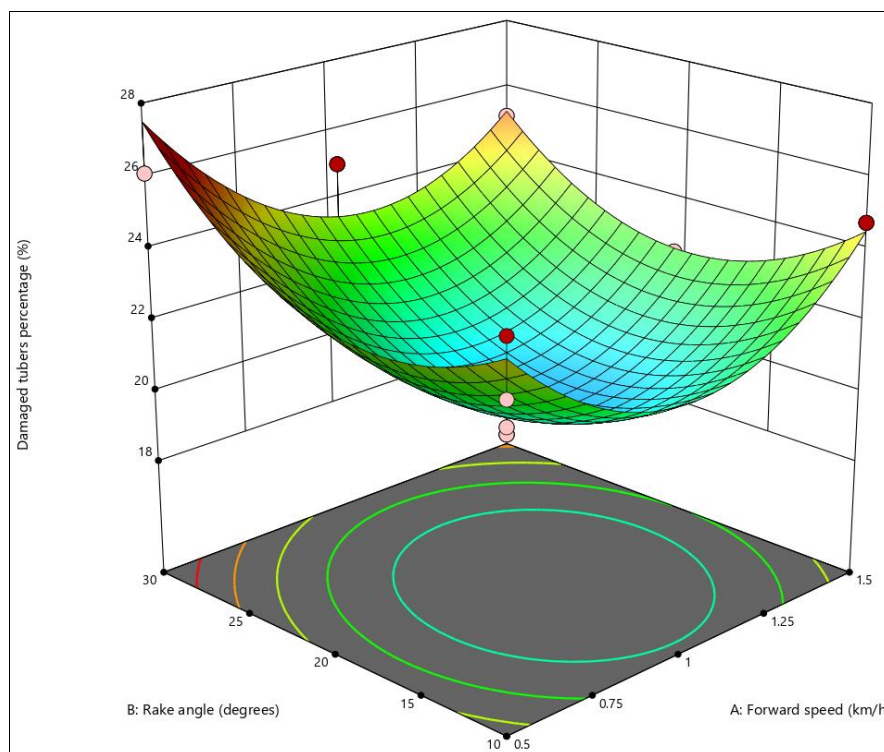


Fig 7: Effect of rake angle and forward speed on damaged tubers percentage

3.1.3 Undug tubers capacity

It is the total quantity (kg) of undug tubers collected from the sample area, later converted to kg/ha. The effect of optimum level of forward speed and rake angle were studied on undug tubers capacity and are presented in Fig. 3.3. It was observed that the undug tubers capacity increases with increase in rake angle also with increase in forward speed. The maximum (4996 kg/ha) undug tubers capacity was observed at rake angle 30° and forward speed 1.5 km/h, similar results were seen at rake angle

10° and forward speed 0.5 km/h. Decreasing rake angle causes running of the blade above the desired digging level due to that less scoring of soil happens and more amount of tubers remains undug. Also, at rake angle 30° blade faces great flow of dug material due to which wheels of power tiller starts to rotate at single point, due to this operator needs to lift the digging blade by slanting power tiller forward to lift the digging blade.

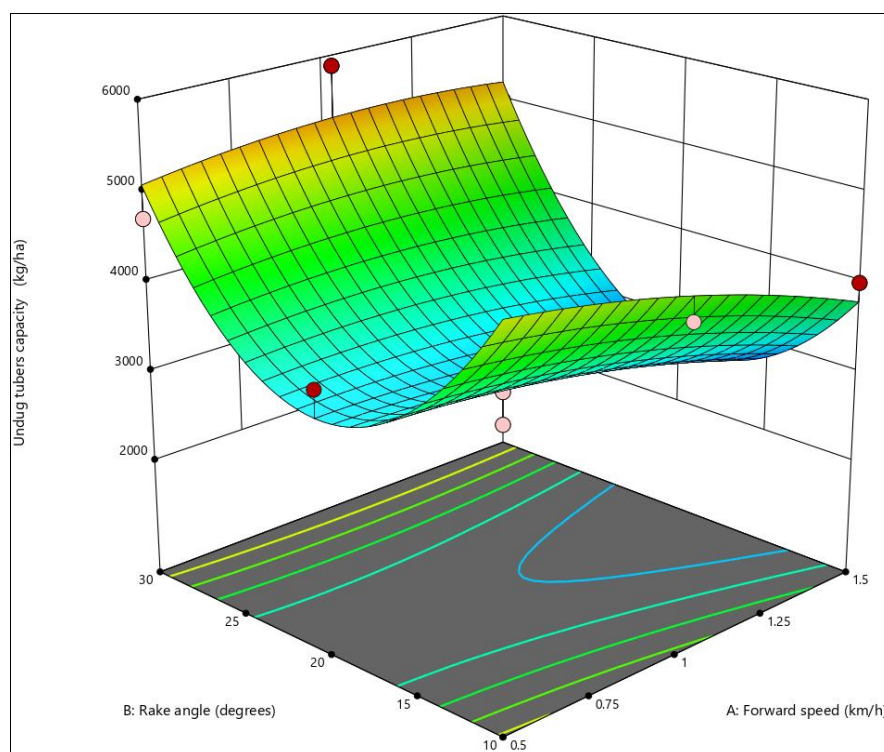


Fig 8: Effect of rake angle and forward speed on undug tubers capacity

3.1.4 Damaged undug tubers percentage

The effect of optimum level of forward speed and rake angle were studied on the damaged undug tubers percentage and are presented in Fig. 3.4. It was observed that with increase in forward speed and rake angle the damage of undug tubers increases. The maximum (48%) damage was observed at forward speed 1.5 km/h at rake angle 30°, similarly at forward speed 0.5 km/h and rake angle 30° the maximum (43%) damage

was observed. This might be due to low desired depth of digging blade, because of the sharp edge of the blade and low depth level the tubers might have got cut. Near about half percent of undug tubers were acquired damaged. Agbetoye *et al.*, 1998^[1] stated that, the tool geometry governs by rake angle of the blade and friction angle of the soil. Similarly, due to circular shape and sharp edges of the blade it may have possibly cut and damaged the tubers which were in the range.

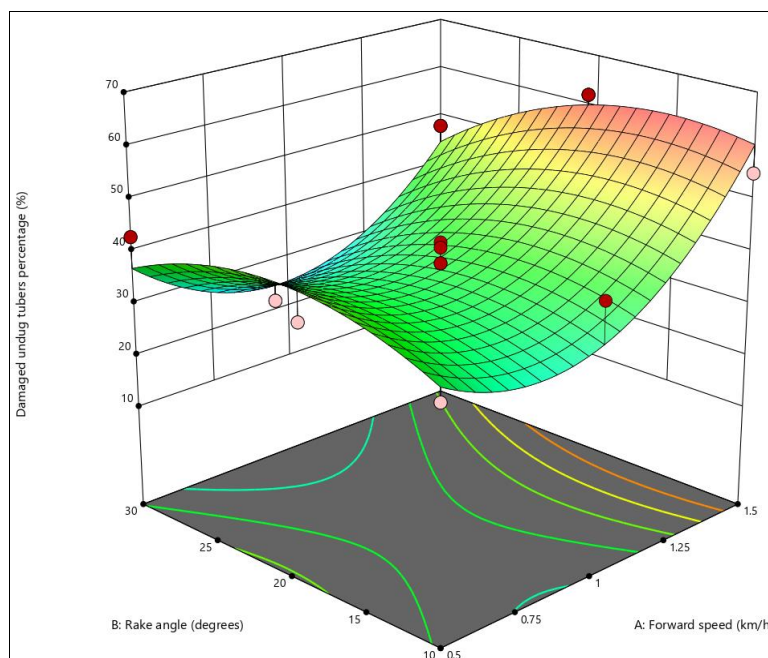


Fig 9: Effect of rake angle and forward speed on damaged undug tubers percentage

3.1.5 Digging efficiency

The effect of optimum level of forward speed and rake angle were studied on the digging efficiency and are presented in Fig. 3.5. The minimum (56% and 59%) digging efficiency was observed at rake angle 30° at forward speed 1 km/h and 1.5 km/h respectively. While the digging efficiency was highest (78%) at rake angle 20° at forward speed 1 km/h. It might be due to at 20° rake angle the pointy nose of the digger blade digs into

the soil and continuous scoring of the material was also observed. The digging efficiency is directly affected by rake angle. Similar results were observed in case of tractor mounted cocoyam harvester in that study Akinbamowo *et al.* 2011^[3] observed that the maximum value of digging efficiency of 90.5% was obtained at 20° rake angle followed by 83.2% at 25° and 78.2% at 15°.

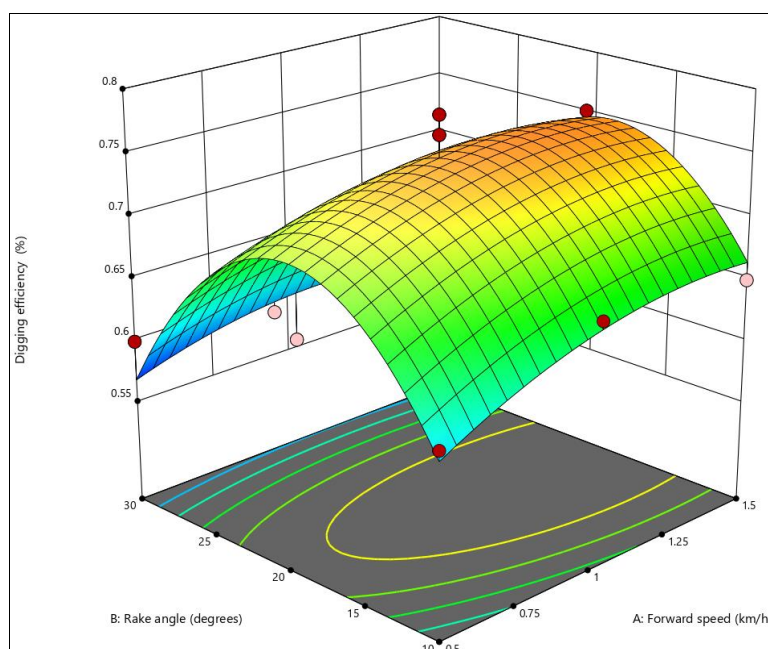


Fig 10: Effect of rake angle and forward speed on digging efficiency

3.1.6 Field efficiency

The effect of optimum level of forward speed, rake angle was studied on the field efficiency and are presented in Fig. 3.6. The field efficiency increased with the decrease in forward speed. The highest (85%) field efficiency was observed at forward speed 1km/h at rake angle 20°. It was observed that forward speed is directly influencing field efficiency. Nandaniya *et al.*

2022^[19] observed that field efficiency decreased as per forward speed increase productive time reduce. Nour *et al.* 2020^[21] observed that Increase in forward speed decreases the field efficiency. Similar results were seen in observation of lesser yam digger. It might be due to reduction of productive time causes decrease of field efficiency. Because of more operational stops leads to increase in nonproductive time.

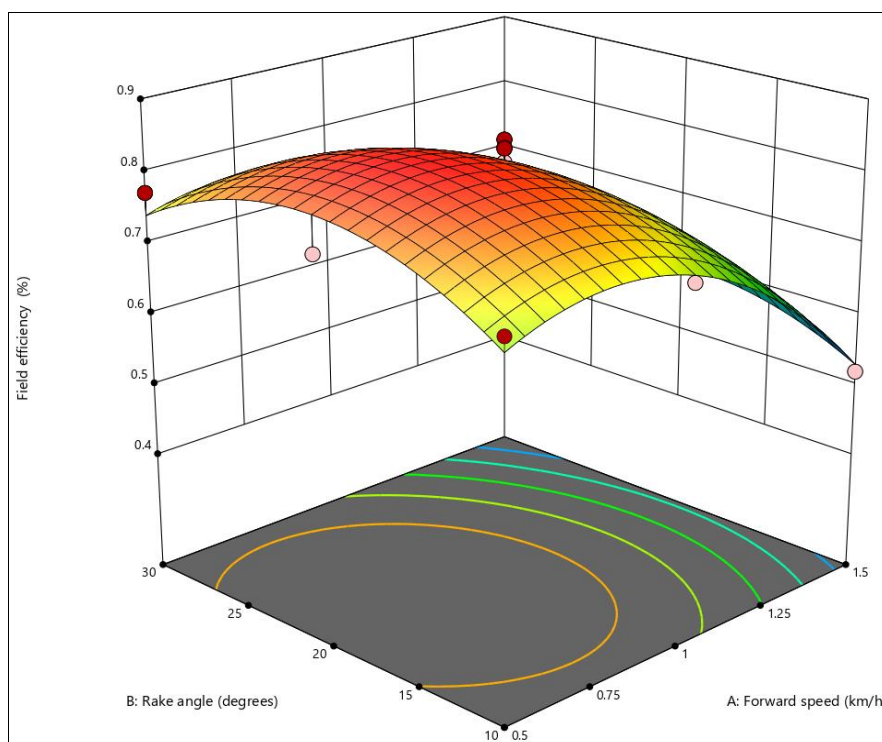


Fig 11: Effect of rake angle and forward speed on field efficiency

3.2 Cost economics of lesser yam digger

The operating cost of lesser yam digger was determined by

using IS-9164-1979 test code



Fig 11: Side view of lesser yam digger attached with power tiller



Fig 12: Developed Lesser yam digger in working

Table 1: Cost economics of lesser yam digger

Sr. No.	Particulars	Cost
1	Total cost of lesser yam digger, ₹.	4040
2	Fixed cost of power tiller, ₹/h	30
3	Variable cost of power tiller, ₹/h	337
4	Total operating cost of power tiller, ₹/h	367
5	Fixed cost of lesser yam digger, ₹/h	4
6	Total operating cost of lesser yam digger with power tiller, ₹/h	371
7	Cost of digging for lesser by developed digger, ₹/ha	7270
9	Cost of manual digging for lesser, ₹/ha (Appendix V)	12000
10	Net saving per ha, ₹	4730

4. Conclusions

1. The developed lesser yam digger can harvest 8520 kg/ha tubers, with 22% damaged tubers percentage, 2400 kg/ha undug tubers, 38% damaged undug tubers percentage, with digging efficiency 78%, and field efficiency of 85%.
2. The optimum operating conditions for lesser yam digger was forward speed 1 km/h and rake angle 20°.
3. Developed lesser yam digger worked properly up to 260 mm depth.
4. Rake angle of blade majorly affects tuber damage and digging efficiency.
5. The development cost of the digger was found to be ₹ 4040 and its operating cost as ₹ 7270 /ha.

5. Limitations

The power tiller is machine generally made to perform the rotary tilling operation. Due to this this machine does not perform promising when digging operation is concerned. While performing the digging operation, draft ability of machine used is main concern which cannot be overlooked because, when we performing the digging operation (Hensh *et al.*, 2022) [7]. This study noted that 9.96 KW power tiller is reaching its maximum wheel slippage at 180 mm producing 2.232 KN drawbar pull. Due to such conflicting availability of machine power there is tremendous scope in the improvement of the machine.

There are few limitations accessed while performing the whole study. Traction part of the work is of major concerning section while performing actual field trials. Unevenness of field, maintaining wheel sleep while maintaining depth of operation such that there should be minimum damage to the rhizomes is the concerning part of the tests. This is the first trial study done

in the harvesting of the yams in the Kokan region, it might be not very exhaustive study, but most of the concerning part regarding the harvesting of the lesser yams harvested in the Kokan region were touched. Which will improve the harvesting equipment over the time.

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