Indian Journal of Engineering & Materials Sciences
Vol. 29, April 2022, pp. 283-290

Design and development of a digging machine for turmeric and ginger crop

Narender[a]*, & Atul Kumar Shrivastava[b]

[a]Department of Farm Machinery and Power Engineering, COAE&T, CCS Haryana Agricultural University, Hisar, Haryana 125 004 India

[b]Department of Farm Machinery and Power Engineering, COA, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh 482 004, India

Received: 10 march, 2021; Accepted: 3 February, 2022

The turmeric and ginger crop was harvested by different types of spade, fork or bullock drawn plow. These methods are very tedious and ergonomically not suitable for the human labour and that results high labour cost and more time and energy consumption for harvesting of the turmeric and ginger. Due to shortage of labour and high charges demands the mechanization in harvesting of these two crops. So a tractor operated digger was design and developed for harvesting of the turmeric and ginger crop, which could dig the crop and separate the fresh crop from soil in field. The digging efficiency of machine was found to be 98.01 and 97.76 % with the exposed percent of 86.42 and 85.93 for ginger and turmeric crop, respectively. The per cent decrease in cost of digging by digger in comparison to manual digging was found to be 69.53 and the break-even point of the digger was 57.59 hours per year. The payback period of root crop digger was less than one year.

Keywords: Development, Digging, Ginger, Turmeric

1 Introduction

India has been the leading spice-producing, consuming and exporting country in the world since the recorded history. Traditionally, spices in India have been grown in small land holdings but organic farming has gained prominence in recent years. Spices especially ginger and turmeric are being used as immunity boosters to avoid infection and has good anti-oxidant and anti-inflammatory properties[1] and after the Covid-19 pandemic; the demand is continuously increasing now that the spice factories have started opening up after the lockdown. However, despite the COVID Pandemic, spices export from India has increased during 2019-20. The estimated export during 2019-20 has been 1183000 tons valued Rs. 21,51,540 lakh against 1100250 tons valued Rs.19,50,581 lakh during the financial year 2018-19[2]. Compared to year 2018-19, the export has shown an increase of 10% in rupee value and 8% in quantity[2]. USA, China, Vietnam, Thailand, Bangladesh, UAE, U.K., Malaysia and Sri Lanka were the major importers of the spices from India. In addition, huge quantities of spices are consumed within the country for immunity booster, seasoning of foods and for several other medicinal purposes. Among the spices, the USA and Morocco were the leading importers of the turmeric and ginger from India in year 2018-19[2]. These figures indicate the economic importance of spices in India and the World. India is the largest producer of ginger and turmeric, accounting for 50 and 70-75 per cent of the world production, respectively. In India, the production of ginger and turmeric crop was estimated 1843 and 939 thousand tonnes with an area of 172 and 246 thousand hectares, respectively during the year 2019-20[2]. The harvesting of turmeric and ginger depends on maturity and it has the ultimate use. The turmeric and ginger rhizome is harvested by traditional methods ie. manually by different types of spade, fork or bullock drawn plow[3,4]. The clumps are lifted up and the rhizomes are separated from the dried up leaves. These methods consume more time, cause drudgery, losses and low field capacity. Harvesting becomes more important for storage purpose. To reduce the spoilage of ginger and turmeric during storage, healthy ginger and turmeric rhizomes are selected at the time of harvesting[5]. Generally, the rhizomes spread down at 14 to 20 cm deep in the soil, it will not be possible to achieve digging of the entire rhizomes by manual digging and hence, the considerable quantities of rhizomes are damaged and remains undug. Moreover, the increasing non-availability of skilled labour for harvesting and the prevailing higher harvesting

*Corresponding author (E-mail: narender4ever@gmail.com)

charges especially in peak season demanded to make it all the more essential. Therefore, there has been a need to develop a mechanical means of digging for turmeric and ginger crop. At present, there is no efficient, lightweight and low-cost digger or harvester developed in India locally which could be used efficiently for almost all types of crops i.e. garlic, onion turmeric, ginger, and potato etc. So, it is necessary to introduce a machine that could dig these crops and reduce the digging time, human efforts and increases the mechanization on farmer's ground level. Taking these points into account, it was therefore, proposed to study various machine crop parameters and to design and develop a suitable digger for turmeric and ginger.

2 Materials and Methods

2.1 Design of digging blade

Blades are used for digging or scooping up the soil and crop, the choice depends upon the width, thickness and the various forces acting on the blade. In this case of digger, the width of the share was taken 75 cm on the basis of crop bed and track width of tractor. The blade thickness was designed on the basis of force required for digging of soil and crop.

2.1.1 Determination of draft on digging unit

The draft of the blade was calculated by using the general soil mechanics equation for a blade deforming the soil in two dimensions[6]as given below which was also used[7]. The soil working tool having a depth/width ratio greater than 1 is known as a narrow tyne and depth/width ratio less than 0.5 is called a blade[8].In case of digger, the width of share was taken 750 mm on the basis of crop bed width. On the basis of the crop profile in vertical plane of the bed of the field, the maximum depth of the turmeric and ginger crop was found to be 200.30 mm and 172.20 mm, respectively and blade operating at these depths of the crop would give a depth/width ratio of 0.267 and 0.229, respectively, which is less than 1. Therefore, the digging share could be assumed as a blade. The usual variations in rake angle of the digging share have been reported between 15 to 25^{o} by many researchers. A rake angle of 20^{o} gave minimum draft and maximum upward force as reported by Payne[9]. This was further confirmed by Osman[10] & Khurana[11] in the case of a blade. Therefore, the maximum rake angle of the share was assumed on the higher side (*i.e.* 25^{o}) for determination of draft.

The two-dimensional soil failure approach using the general soil mechanics equation suggested in ref[6] was adopted to calculate soil resistance force in flat blades cutting soil in a passive failure zone. The soil resistance forces acting on the digging blade are shown Fig. 1. The proposed equation takes into account different soil properties and tool geometry which is given below:

$$F_p = (\gamma d N_\gamma + C N_c + C_a N_{ca} + q N_q) d \qquad \ldots (1)$$

where,

F_p = Passive resistance of soil acting at an angle of soil-metal friction with the normal to interface, kg per meter width;

γ = Bulk density of soil, kg/m^3;

d = Depth of operation, m;

C = Cohesion of soil, kg/m^2;

C_a= Soil-interaction adhesion, kg/m^2; and

Q = Surcharge pressure on soil from surface above the failure plane, kg/m^2.

N_γ, N_c, N_q, and N_{ca} are dimensionless N- factors, which depends upon soil metal friction angle (δ), soil internal friction angle (φ) and rake angle of blade (α).

(a) Tool parameters-

Operating depth of furrow opener (d) = 200 mm (As per the maximum depth of the crop)

Width of operation (w) = 750 mm (bottom width of the ridge)

Depth width Ratio (d/w) = 0.266

Range of rake angle = 15^0 -25^0 (25^0 is taken for the draft)

(b) Soil parameters-

Bulk density of soil, γ = 1470 kg/m^3

Cohesion and internal friction are referred to as real physical properties of the soil and used in engineering design for the estimation of the shear strength of the

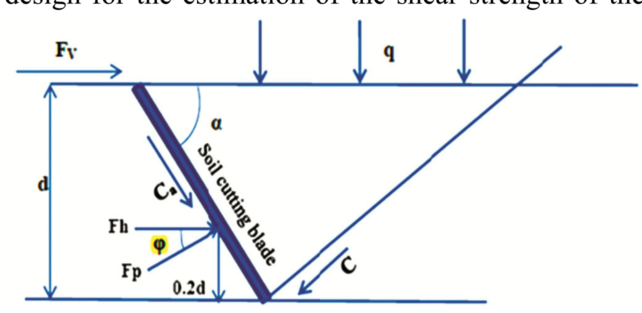

Fig. 1 — Soil forces acting on a simple digging share.

soil[12, 13]. So, taking the cohesion (c) to 0.895 kg/m^2 and angle of internal friction (Φ) equal to 22.54 degree[14].

Angle of soil metal friction (δ)= $\frac{2}{3} \times \varphi = 15.03^{\circ}$

The adhesion of the soil can be taken as zero i.e. Ca = 0 assuming soil-metal friction zero as soil scouring over the blade

The surcharge q = 0 (Assumed).Based on this assumption, Eq. (1) can be determined as follows-

$$F_P = (\gamma d N_\gamma + C N_c)\, d \qquad \ldots (2)$$

The relationship between the N- factor and the rake angle at different angle of internal friction for a perfectly smooth (δ=0) and perfectly rough (δ= Φ) interface was interpolated by using the Eq. 3[6].

$$N_\delta = N_{\delta=0} \left[\frac{N_{\delta=\emptyset}}{N_{\delta=0}}\right]^{\frac{\delta}{\emptyset}} \qquad \ldots (3)$$

where,

N_δ = the required value of the appropriate N= factors (N_γ or N_c);

$N_{\delta=0}$ & $N_{\delta=\Phi}$

The corresponding value of the N-factor at δ=0 and δ= Φ, respectively obtained from appropriate chart[6] and same were used for the determination of passive resistance of blade.

γ = 1470 kg/m^3, C= 0.895 kg m^{-2}, Φ = 22.549^0, δ = 15.03^0, α = 25^o and d=0.2 m

Using the relationship as given in equation 3, the value of N-factors was calculated as follows:

N_γ= 1.3 when δ=0

N_γ= 1.4 when δ=Φ

N_c= 1.7 when δ=0

N_c= 1.6 when δ= Φ

Now using Eq. (3)

$$N_{\gamma,\delta=15.03^o} = 1.3 \left[\frac{1.4}{1.3}\right]^{\frac{15.03}{22.549}} = 1.36$$

$$N_{c,\delta=15.03^o} = 1.7 \left[\frac{1.6}{1.7}\right]^{\frac{15.03}{22.549}} = 1.63$$

N_γ = 1.36, N_c = 1.63

Substituting the values of N_γ and N_c, determined as above, in the Eq (2) the passive resistance (Fp) per unit width of the blade was obtained as:

Fp = 1470 x 0.2 x 1.36 + 0.895 x 0.2 x 1.63 = 80.25 kg/m

Therefore, Fp for an effective width of cut per 75 cm of blade = 60.187 kg

The passive resistance F_P is acting at an angle of friction (δ=15.03) with the normal to the interface. Hence the component parallel (F_R) to the blade face is given as:

F_R = 60.187 × Cos74.97^o=15.60 kg

And component perpendicular to the blade face (F_{p2}) is given as:

F_H =60.187 × Cos15.02^o = 58.12 kg

The obtained value of F_R and F_H were used to determine the bending moment of the digger blade. The F_R is the horizontal component of F_P and would induce direct stress in the share whereas; F_H is the perpendicular component of F_P would cause a bending moment. The force will act at the center of resistance of the share. The average soil resistance of shovel acts at a distance of 0.2d was measured from the cutting edge[15].

Centre of the resistance = 0.2d =0.2 x 200 mm = 40 mm

Therefore, the center of the resistance would be at a distance of 40 mm from the cutting edge on the central axis of the width of blade. The share is supported on the nuts and bolts at a distance 200 mm from the cutting edge. Therefore, the distance between the center of resistance and the point of support is given by:

200 - 40 = 160 mm = 16 cm

Therefore, the Bending Moment (B.M.) due to F_H will be

B.M. =58.12 x 16 = 929.94 Kg-cm

Bending stress (σ_b) is given as:

$$\sigma_b = \frac{B.M.}{\frac{1}{6} \times b t^2} \qquad \ldots (4)$$

where,

B M = Bending Moment, kg-cm;

b = width of blade at the point of mounting, cm and

t = Thickness of the sheet for blade, cm

$$\sigma_b = \frac{929.94}{\frac{1}{6} X 10 X t^2} = \frac{557.96}{t^2} \text{kg-cm}$$

And direct stress (σ_d) due to F_{p1} was calculated as-

$$\sigma_d = \frac{F_{P1}}{bt} = \frac{15.60}{10\,Xt} = \frac{1.56}{t}$$

Total stress (σ) = $\sigma_d + \sigma_b$

$$\sigma = \frac{1.56}{t} + \frac{557.96}{t^2}$$

Considering the factor of safety as 1.2 and equating the total stress (σ) with the safe stress of 600 kg/m^2 of mild steel, then the thickness (t) of the blade was determined as-

$$600 = \left(\frac{1.56}{t} + \frac{557.96}{t^2}\right)1.2$$

t = 1.057 cm ≈ 10 mm

Hence, the thickness of the blade was kept as 10 mm and the total width of the blade was kept as 750 mm as per requirement of digging operation. The blade was made of M. S. flat of dimension of 1000x70x10 mm. at front the blade was sharpened for easy penetration. The width of the blade was decided on the basis of the width of the crop sown on the bed. Further the blade was attached with an M.S. sheet of the dimension of 1450x300x3 mm for easy conveyance of the material to the separating unit as shown in Fig. 2. Both sides of the sheet were attached to the mainframe with an M.S. Flat through fastening of the nut-bolt. In this unit, provision was made to change the rake angle of the digging operation.

2.2 Design of soil separation unit

The soil crop material dug by a digging unit would be directly forwarded to a separation unit. The soil separation unit (Fig. 3) was placed just behind the blade to receive the dugout crop and soil mass. Fig. 3 shows the orthographical and isometric view of soil separating unit. To separate the soil from crop plant, stainless steel of round shape were arranged lengthwise along the line of travel of the digger. The soil attached to the digger was removed with the help of oscillation produced by the crank mechanism. Physical properties of turmeric and ginger i.e. length, width and thickness were used to determine the various dimensions of soil separator. As per the properties of coefficient of friction of rhizomes of both the crop was found that the friction which causes skin bruisness of rhizome was minimum in the case of stainless steel as compared to mild steel, galvanized iron and aluminum[16]. Keeping in the point of seeds and storage purposes of both crops, the stainless steel separation unit was recommended and it's fabricated.

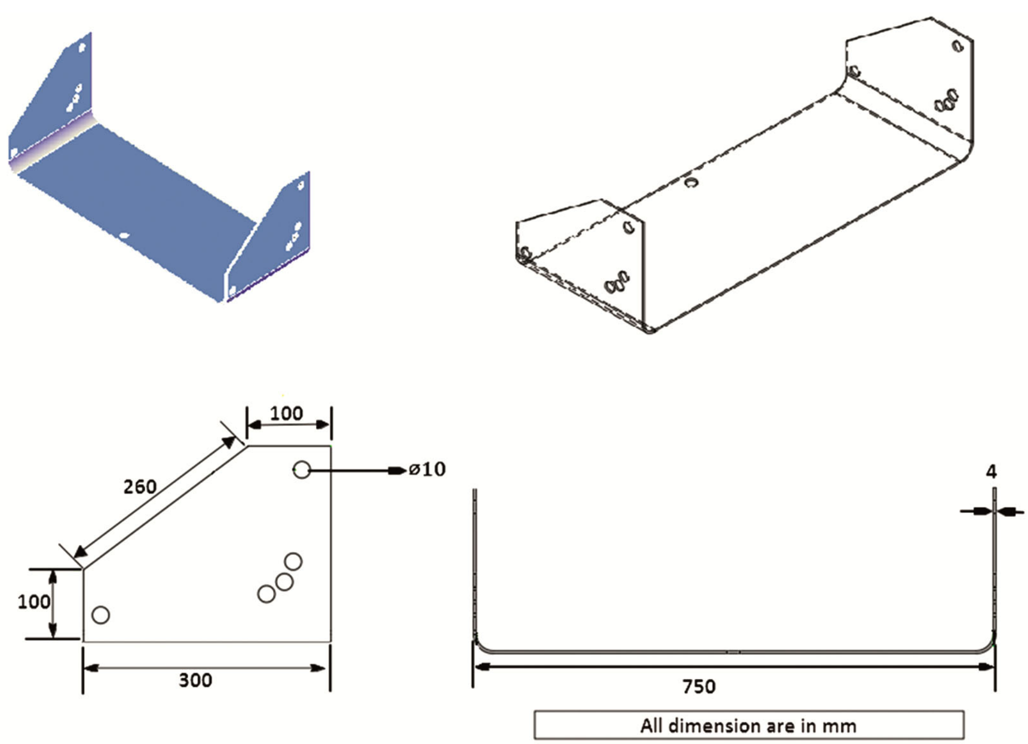

Fig. 2 — Orthographical view of blade attachment unit of the digger.

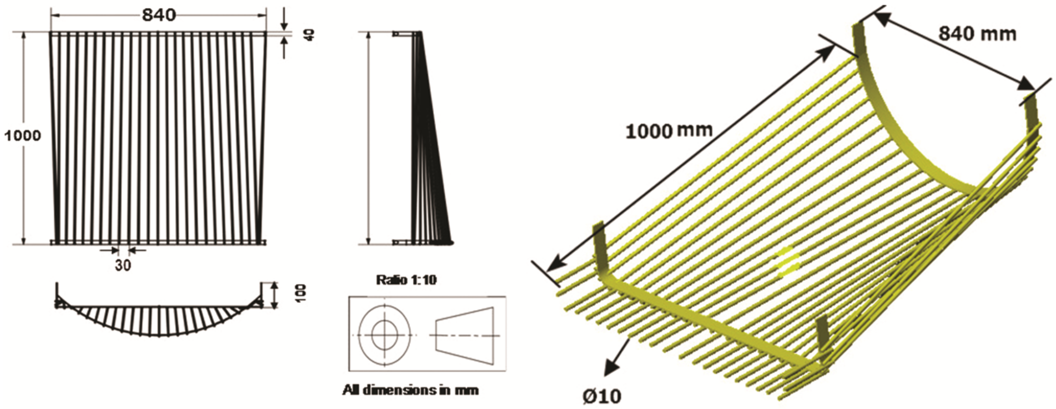

Fig. 3 — Orthographical and Isometric view of soil separating unit of a tractor operated digger.

2.2.1 Determination of length of soil mass conveyor

For the determination of the volume of material flow on the soil conveyor, the volume of the material flow on the separator was determined as follows:

Volume of soil = Area of coverage of the share x forward speed of travel

Assume the forward speed = 3 km/hr

Working width of machine = 0.75 m

And working depth = 0.20 m

So the volume of soil $=\frac{0.75 X\ 0.20\ X\ 3\ X\ 1000}{60\ X\ 60}= 0.125\ m^3/s$

Weight of soil = 0.125 x 1470 = 183.75 kg/s

Assume the weight of the crop in one meter length of bed is 3 kg.

Then the weight of crop per sec = weight of crop in one meter length of bed X speed

= 3 X 0.833 = 2.49 kg/s

Total material to be handled (Q_{out}) =186.24 kg/s

Now equating the volume of material flow with the volume of the separator by assuming that this material will be spread uniformly on the separator in 7 cm thick layer, the following was obtained as given below. As the speed of separator was depends upon the eccentricity of crank of the digger.

Q_{out} = γ x length x thickness of material x speed of separator

=186.24 =1470 x l x 0.07 x 3

L = 0.61 ≈1.0 m

Therefore, the separator of 1.0 m length was fabricated using stainless steel rod of 10 mm diameter and the opening between the rods was selected 30 mm keeping in view the approximate minimum size of the turmeric and ginger branch to be retained on the separator and gave maximum opening of the conveyor area for sieving of the soil. This would facilitate the soil separating unit for maximum soil separation from the crops. The gap between the two consecutive rods of soil separator was kept in the range such that the crop should not pass between two consecutive rods. Provision was provided to vary the angle of separating unit with the help of a lever attached to the frame as shown in Fig. 4. For free and efficient dropping of soil-mass from the separator, the rod spacing was kept as 30 mm. Actually under field condition in case any type of soil, the soil clods were obtained while during the digging, the size of clods may be 20 to 30mm or more as well as the rhizomes of turmeric and ginger have big or more branches in oneplant. Therefore, the gap 30 mm were kept in actual field design to passes more soil without any damage.

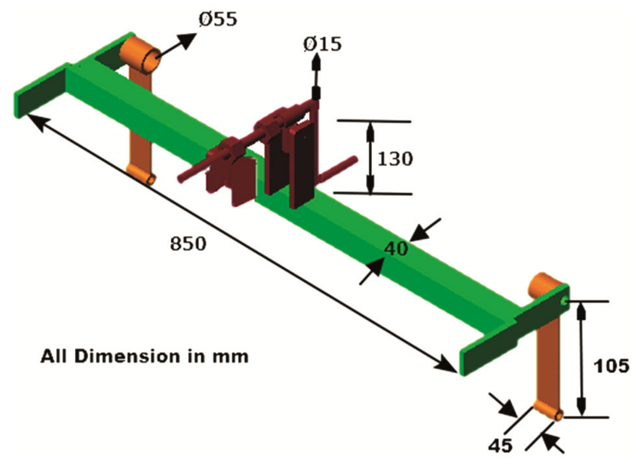

Fig. 4 — Isometric view of the angle mechanism of the soil separating unit.

2.3 Design of power transmission unit

The power is transmitted to soil separating the unit through a slider-crank mechanism. Propeller shaft, crank and connecting rod are main parts of it. The separating unit was provided motion to remove/separate soil from the crop by the power transmission system. The power is transmitted in two stages, at first from P.T.O. to crank, where the power is transmitted through the propeller shaft, and from crank to the separating unit by the connecting rod. One end of the shaft having the diameter and length are 42 and 300 mm, respectively with 10 splines on it are attached to the tractor PTO and another end to the crank through bearing. The connecting rod is made of M.S. flat of size 460x40x5 mm. The connecting rod is attached to crank with ball bearing of diameter 45 mm and the other side was attached to the reciprocating frame through a M.S. flat of size 310x55x10 mm (Fig. 5).In this mechanism, the rotary motion of the crank is converted into reciprocating motion of separating unit. The diameter and thickness of the crank are 140 mm and 10 mm, respectively. The number of revolutions of the crank was depended upon the PTO speed of tractor. The provision was made for reduction of power through the slider-crank mechanism also, for changing the stroke length of soil separation unit as shown in Fig. 6, the crank was offset from the center. The stroke length of the separation unit is determined by three eccentric points (i.e. 0, 70 and 140 mm) marked from the center of the crank. The crank radius was decided by the following formula [17, 18].

$$X = r [(1-\cos\Theta) + n- (n^2 – \sin 2\Theta)^{1/2}] \quad \dots (5)$$

where,

X = stroke length, 14 cm;

r = crank radius, cm;

Θ = angular displacement of crank;

n = l / r; and

I = connecting rod = 31 cm.

For maximum displacement, $\theta = 180^o$. Hence, sin $2\theta = 0$

From the Eq. (3.14), the crank radius was given as

$X = r [\{1-(-1)\} + 31/r - (([31/r)]^2 - \sin 180^o)1/2]$

$13 = r [\{1-(-1)\} + 31/r – \{(31/r)\}^2]1/2$

13 = r (2)

r = 13/2 = 6.5 = 7 cm

Taking displacement as 14 cm, the crank radius was found to be 7 cm. This shows that the stroke length was twice the offset crank radius. The crank radius can be varied from 0-7 cm to change the stroke length of reciprocating unit. The machine was tested at 3 offset points of crank from the center i.e. 0, 3.5 and 7cm in the lab. So, distance traveled by the soil separation unit during the half and full revolution was calculated.

2.4 Hitch system

The three points hitch system was welded on the main frame as shown in Fig. 6. The hitch system was arranged as per the specification of IS 4468 (Part 1): 1997[19]. The mast height of the hitch system was kept at 610 mm. for controlling the depth and providing the stability of digger, two wheels are attached with the help of fasting system.

2.5 Main frame

The main frame was fabricated with M.S. rectangular section (100 × 50 × 5 mm) for the size of 1500 x 820 mm. On this frame MS iron square section was welded

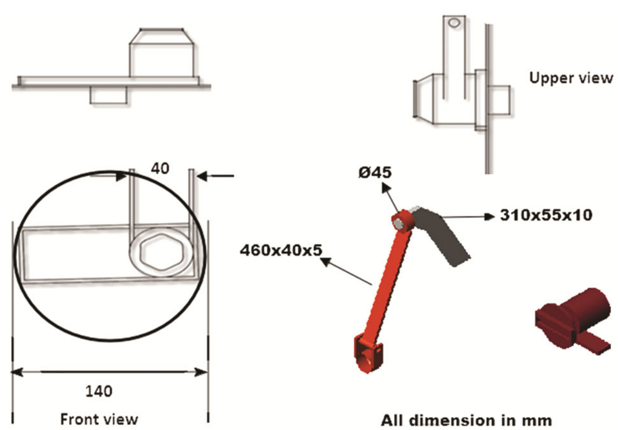

Fig. 5 — Conceptual design of slider crank mechanism.

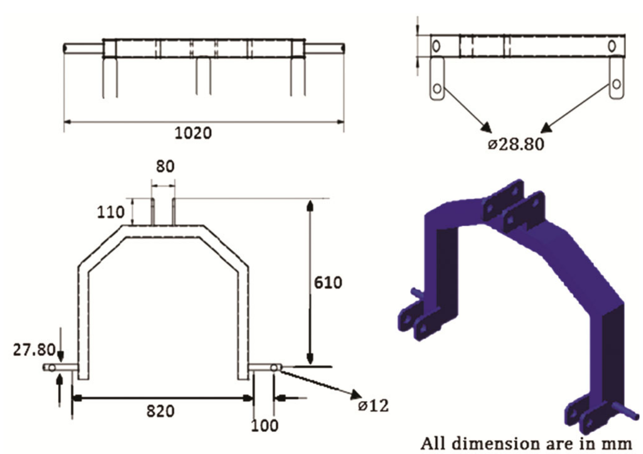

Fig. 6 — Detailed dimensions of the hitch system.

at 330 mm distance from the front side or say hitching point. Whereas, another section was bolted with the help of pedestal at a distance of 760 mm from front side of the machine. For attaching the blade, two MS flat (500 x 50 x 12 mm) was also welded on both side of the frame as shown in (Fig. 7). The power transmission and soil separating unit was mounted with a square hollow section of 50×50 mm by welding and bearing at a distance of 330 and 760 mm, respectively from the front of the frame. The blade support was mounted to the main frame through two flats of size 500×50×12 mm welded to the mainframe (Fig. 7) on both sides. The different digging blade was bolted to the blade support. The details of different views of tractor-drawn digger are shown in Fig. 8 (a and b).

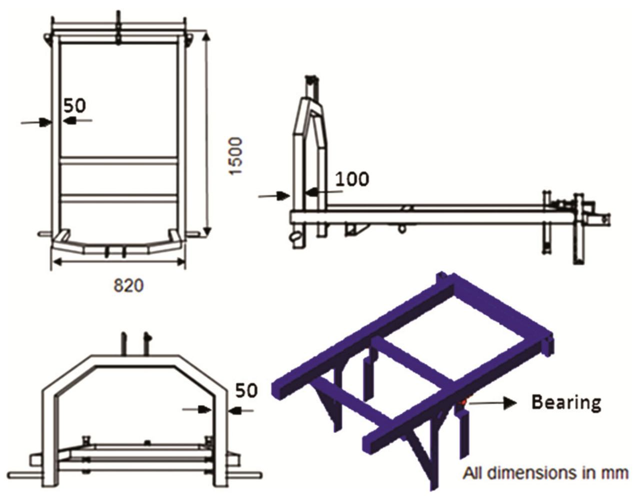

Fig.7 — Detailed dimensions of the frame.

3 Results and Discussions

3.1 Prototype and field trial

The field trial of the developed digger was conducted at the Horticultural Research Farm (22°49' to 24°08' North Latitude and 78°21' to 80°58' East Longitude), Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, MP, India in turmeric and ginger crops. While testing, the digger was installed on level ground. The machine was run at no load to ensure that each component of the digger was working properly. The details of the field trial for the turmeric and ginger crop are given below.

3.2 Performance evaluation of the developed digger in field

The soil character was laterite and both crops were sown on the ridge of size 68 cm at bottom and 30 cm at top. The irrigation was given by the inline drip system. At the time of digging, average moisture content was found 12.60 % and 11.97 % on dry basis, the bulk density of soil was recorded 1.53 g cc^{-1} and 1.58 g cc^{-1} and cone index was ranged from 874 to

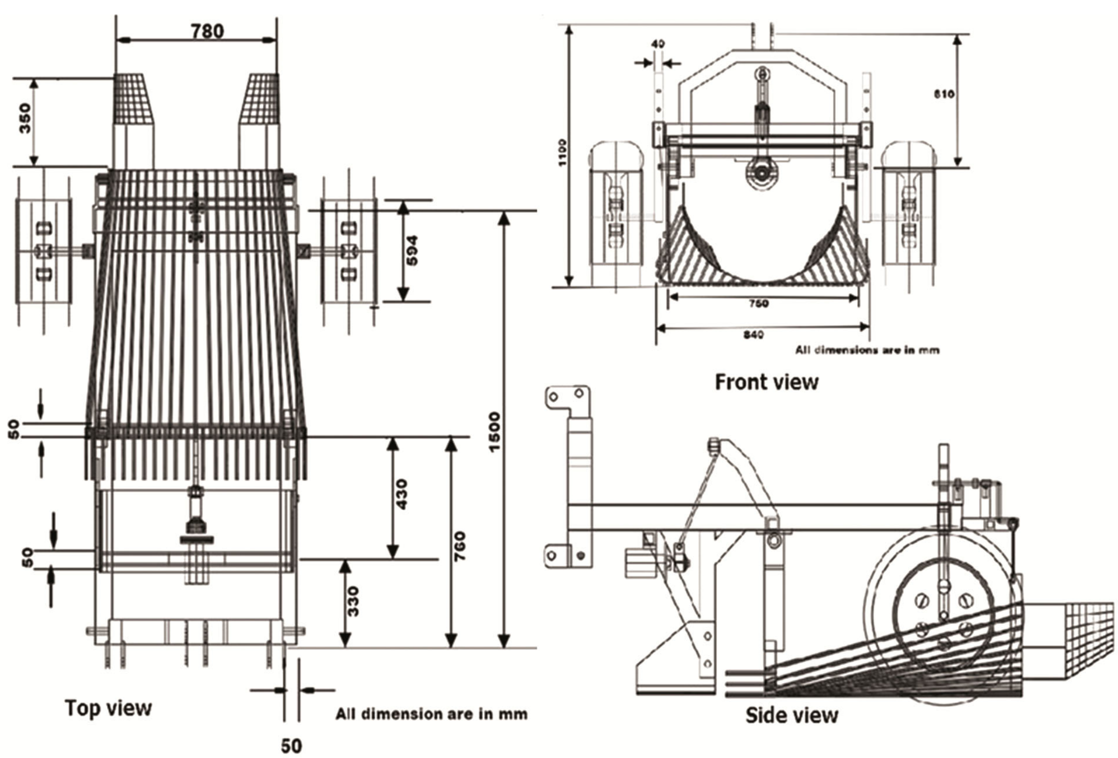

Fig. 8 (a) — Top view of developed digger.

1181 kpa and 852 to 1127 kpa in field of turmeric and ginger crop, respectively upto the depth of operation of the digger. The tractor-drawn digger was evaluated with 45 hp New Holland tractor at the optimized value for the ginger and turmeric crop.

The performance of the digger was found to be satisfactory in respect of digging efficiency of 98.01 and 97.76 % and exposed per cent of 86.42 and 85.93 ginger and turmeric crop, respectively. The damage was 1.98 and 3.30 per cent which was much low as compared to manual digging of ginger and turmeric crop i.e. 9.73 % and 10.25%, respectively. The field capacity of the developed digger was found to be 0.133 ha/h with a field efficiency of 87.82 %. One skilled labour is needed for operation of the tractor with developed digger and four unskilled labours were required for collection of the digged crop. The labour requirement of the developed digger was 37.59 man-hours per hectare as compared to 500 man-hours per hectare in manual digging.

4 Conclusion

A tractor operated digger was developed for ginger and turmeric crop which can dig and separate crop. The main component of the digger were digging blade, power transmission system, soil separating unit, conveyor and main frame. Most of the crop (98%) was dug by the developed machine with the exposed percent of 86.42 and 85.93 for ginger and turmeric crop, respectively. The field trial showed that saving in labor of manual digging by digger was 92.40% both in ginger and turmeric crop. 37.59 man – hours per hectare was required in comparison to manual digging of 500 man-hours per hectare. The benefit-cost ratio of the digger was 6.60 with break-point of 57.59 hours per year.

The field test shows that machine works smoothly and efficiently with a filed efficiency of 88% for both the crops. But needs improvement for collecting unit that may be attached behind the digger. The machine success rate may be tested in the sandy loam soil and other root crops also.

References

1 Balkrishna A , Shankar R, Srivastava A, & Joshi B & Mishra R K, *Indian J Tradit Know*, 19 (133) (2020) 118.
2 Spices Board India, Ministry of Commerce & Industry, Govt. of India, 2019, https://www.indianspices.com/ sites/default/ files/majorspicewise.pdf
3 Plotto A, Mazaud F, & Röttger, *TURMERIC: Post-Production Management*, Food and Agriculture Organization of the United Nations (FAO), AGST, 2004.
4 Munde PA, Sawant BP, & Sawant SA, *Int J Agric Eng,* 3(1) (2010) 17.
5 Babu N, Srivastava S K, & Agarwal S, *Indian J Tradit Know*, 12 (3) (2013) 518.
6 Hettiaratchi DRP, Witney BD, & Reece AR, *J Agric Eng Res*, 11(2) (1966) 89.
7 Khura TK, *Design and development of tractor-drawn onion (Allium cepa) harvester*, Ph D thesis, Division of Agricultural Engineering, Indian Agricultural Research Institute, New Delhi, 2008.
8 Godwin RJ, & O'Dogherty MJ, *J Terramechanics*, 4 (2007) 03.
9 Payne PCJ, *J Agric Eng Res*, 1(1) (1956) 23.
10 Osman MS, *J Agric Eng Res,* 9(4) (1964) 313.
11 Khurana R, Manes G S Dixit A, Singh A, Mahal J S & Singh B P, *Prototype feasibility testing of tractor operated root crop harvester*. Annual Report, Punjab agricultural university, Ludhiana, 2012.
12 Han Z, Jiangwen Li, Gao P, Huang B, Ni J, & Wei C, *Int J Environ Res Public Health*, 17(1555) (2020) 01.
13 Kepner RA, Bainer R, & Barger EL, *Principles of farm machinery,* (CBS publishers & distributors pvt. ltd. New Delhi, India), 3rd Edn, ISBN: 81-239-0977-2, 2003,p. 400.
14 Jain S, & Jain R, *Int J Eng Res Technol*, 4(11) (2015) 256.
15 Bernacki H, Haman J, & Kanafojski CZ, *Agricultural Machines, theory and construction* (Scientific publication, Central Institute of Scientific, Technical and Economic Information, Warsaw, Poland), 1,OCLC-691780707, 1972, 359.
16 Mishra AK, & Kulkarni SD, *Agricultural Engineering Today's*, 33 (2) (2009) 26.
17 Ballaney PL, *Theory of machines* (Khanna Publisher, New Delhi), 25th Edn. ISBN: 978-81-7409-122-2, 1990, 853.
18 Liljedahl JB, Jackson GL, De Graff R P, & Schroeter M E, *Agric Eng*, 42 (6) (1961) 298.
19 IS 4468: Agricultural wheeled tractors - Rear-mounted three-point linkage - Part 1: Categories 1, 2, 3 and 4, (1997) 1