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Performance of power tiller mounted turmeric harvester at optimized crop and operational parameters

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Abstract

India is a major turmeric (*Curcuma longa L.*) growing country and Tamil Nadu is one among the major turmeric growing states. Of the many problems identified in turmeric cultivation, harvesting is a major operation which needs to be mechanized. A power tiller (9 kW) mounted harvester with chisel type single digger blade for digging single row of turmeric crop with a rubber conveyor with vibrator to convey the dug turmeric rhizome was evaluated at optimized crop and operational parameters. The rake angle (20°) of the digging blade and conveying speed (4.5 km h^{-1}) of the rubber type conveyer were optimized by experimentation. The mechanical harvester performed better with rhizome harvesting efficiency of 98 per cent at soil moisture of 15.5 per cent (d.b) with damage of 2 per cent with an effective field capacity of 0.08 ha h^{-1}. The conventional method of manual digging had the average harvesting efficiency of 90.5 per cent and the damage caused to rhizome was 7.1 per cent. The saving in cost was 59.82 per cent by harvesting with mechanical harvester over manual harvesting. The breakeven point was 16 per cent of annual utility and the payback period was 0.5 year for the power tiller mounted turmeric harvester. The better harvesting efficiency by mechanical harvesting would enable the farmer to realize additional 6-7 per cent of the yield with less damage to the produce.

Keywords: Conveyor, cost economics, harvesting blade, rhizomes, turmeric

Introduction

Turmeric (*Curcuma longa* L.) is an important spice of India both for internal consumption and also for export market. It is exported as dry turmeric, fresh turmeric, value added products like turmeric oleoresin as well as turmeric oil. During the crop cycle, adopting modern input technologies including mechanization is required to improve the productivity. Of the many field operations in turmeric, harvesting is identified as a major operation in Tamil Nadu, which needs to be mechanized. Turmeric is grown in ridges at inter row spacing of 450 to 600 mm. The conventional method of harvesting turmeric rhizome is by digging the clump from the soil with a fork type spade. The operation is highly labour intensive and often requires skilled labour. Since the rhizomes spread down 15 to 20 cm deep in the soil, it may not be possible to dig the entire rhizome manually and hence considerable quantity of rhizome is left undug. The damage caused to the rhizome by the fork type spade is also considerable.

Improving the yield of turmeric by minimizing field losses emphasizes the importance to develop suitable mechanical harvesting technology. Moreover, non-availability of skilled labour and the prevailing higher labour wages highlight the need to develop mechanical means of harvesting turmeric. Since power tillers are already available with the farmers, efforts have been made to develop a harvester which could be mounted on tillers for the mechanical harvesting of turmeric.

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Materials and Methods

Crop and soil parameters

The study was conducted at Gobi Taluk, Erode District, Tamil Nadu, India in a silty loam soil using BSR-1 variety of turmeric predominantly cultivated in Tamil Nadu, India. At the time of harvesting, care was taken not to cut or bruise the rhizomes and the whole clump was lifted out with the dry base of the plant. The leafy tops were cut off a week prior to harvest and the crop was given a wetting. Average value of population of crop in one square meter area at six different locations for each variety was measured. The crop spacing adopted was 450 x 200 mm. The rhizome spread weight of rhizome and moisture content were recorded randomly (AOAC, 1970). The number of fingers was counted from 25 harvested hills selected at random. The whole rhizome bulk density was measured in terms of volume and quantity of the crop handled by the machine (Moshenin, 1970). The rhizome index was calculated (Anonymous, 1984).

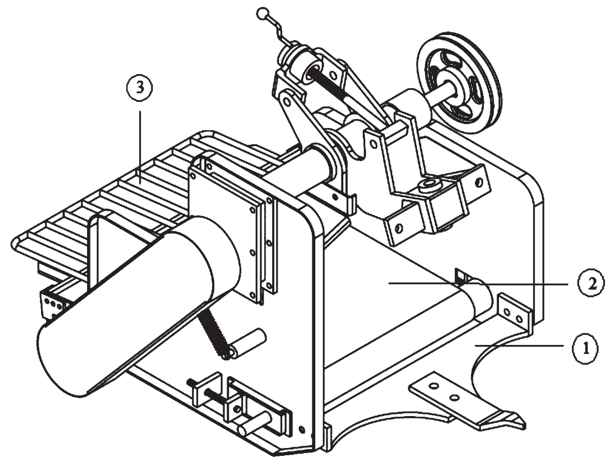
Soil samples at 18 to 20 cm depth during harvest were taken randomly from ten locations and moisture content was determined by gravimetrically on dry basis (AOAC, 1970). Bulk density was measured by core sampler method (Anonymous, 1983a). The draft was measured by adopting a strain gauge transducer load cell dynamometer (Annamalai, 2009). The harvesting efficiency was calculated (Anonymous, 1983b).

Functional parts of power tiller mounted turmeric harvester

The power tiller mounted turmeric harvester consists of two main functional parts *viz.*, harvesting blade and conveyor with vibrating mechanism (Fig. 1). The details of the equipment are given in Table 1.

Table 1. Specifications of the power tiller mounted turmeric harvester

Parameters		Particulars
Type	:	Mounted on a power tiller
Power requirement	:	10-14 hp power tiller
Overall dimension (Lx B x H)	:	0.90 m x 0.85 m x 0.56 m
Number of blade	:	One
Number of harvesting chisel	:	One
Type of conveyer	:	Rubber belt
Type of vibrator	:	Vibrating type with lift rods
Size of the conveyer (L x B)	:	450 mm x 500 mm
Weight of the equipment	:	90 kg



1) Harvesting blade 2) Conveyor 3) Vibrating mechanism

Fig. 1. Isometric view of power tiller attached turmeric harvester

Harvesting blade, conveyor and vibrating mechanism

A straight blade with a digging chisel in the front was used for digging single row of turmeric. The tread width of the wheels of the power tiller could be adjusted from 550 to 850 mm at an interval of 25 mm with the help of a telescopic arrangement.

A conveyer made of hardened rubber was used to convey the dug up soil with turmeric rhizome to the vibration mechanism behind the conveyor. The endless rubber was mounted on a shaft just behind the harvesting blade. The soil with the dug up rhizomes was conveyed from the harvesting blade to the vibrating mechanism. The optimization of the conveyer was done in terms of its conveying speed.

A vibrating mechanism of 500 x 500 mm was provided at the end of the conveyor. The lift rods (twelve numbers) provided along the length of the vibrating mechanism handle the harvested rhizome with soil that is being pushed up by the conveyer mechanism and drop it at the rear end of harvester.

Optimization of operational parameters

The operational parameters *viz.*, rake angle of the harvesting blade and speed of the conveyor were optimized by experimentation. Due to operational restrictions, the speed of operation was fixed at 1.2 km/h, which is the normal speed of a walk behind type harvester (Kepner *et al.*, 1987).

Rake angle of harvesting blade is the suction angle of the soil-tool interface measured along the direction of travel into the horizontal soil surface. The draft is proportional to the weight of soil ridge formed by deformation which is in direct proportion to this angle (Annamalai, 2009). Bolt holes provided for turning the tool backward facilitated to set different rake angles and three levels of rake angle *viz*., 15, 20 and 25^o were selected for the study.

In the present study, three speeds of the conveyer were tried *viz.*, 3, 4.5 and 6 km/h by altering the power transmission mechanism from the power tiller to the conveyer. Care was taken to keep the slope of the vibrator less than the angle of repose of turmeric.

Development of prototype turmeric harvester (Power tiller mounted)

The prototype harvester (Fig. 1) is mounted on a standard hitch frame of MS channel and connected to the 9 kW power tiller by means of power transmission mechanism. A chisel blade of 900 mm length and 200 mm width and 10 mm thick with single tyne is mounted in the front with two support shanks. The conveyor is mounted just behind the digger blade to receive the dugout rhizome with soil. The dug up turmeric rhizomes with soil was conveyed through the vibratory mechanism so that part of the soil adhering to the rhizomes would be separated before dropping it. The blade is positioned in such a way that the power tiller rear wheels would be on the furrows and the blade would dig one ridge between the rear wheels of the power tiller. As the power tiller moves forward at a speed of 1.2 km/h, the harvester frame is lowered down to the desired depth. The rhizomes that are on the ridge are dug out by the blade in front and lifted up along with the soil backward. The rhizomes with soil are discharged at the rear by the conveyor and collected manually.

Field evaluation of the prototype harvester

The performance of the power tiller mounted turmeric harvester was evaluated in terms of harvesting efficiency, field capacity, field efficiency and damage caused to the rhizomes three times in an area of 1 ha each. The optimization of the harvesting blade angle and conveyor speed for achieving maximum harvesting efficiency, conveying efficiency with least damage to the rhizomes was carried out. The experimental results were statistically analysed.

The data collected on conventional method of harvesting and by using power tiller mounted turmeric digger were analyzed for cost of harvesting. For working out the cost economics of the equipment, straight line method was used with rate of depreciation of 10 per cent.

Results and discussion

Conventional method of harvesting

The row spacing was 450 mm and the hill spacing was 200 mm. The average yield was 35 t/ha. The labour requirement for harvesting turmeric was on an average 40 man-days/ha for digging and about 100 women days/ha for picking up the harvested rhizomes. The harvesting efficiency of manual labour was about 91.5 per cent. The damage caused to the rhizome by digging with fork was 6.6 per cent. (Table 2) The cost of digging and picking of

Fig. 2 &3. Performance evaluation of power tiller mounted turmeric harvester

Table 2. Performance tests for manual harvesting of turmeric (*Variety, BSR- 1*)

Particulars	
Field performance	
Rhizomes left undug (%)	8.5
Harvesting efficiency (%)	91.5
Damage (%)	6.6
Labour requirement man-days ha^{-1}	
Men	40
Women	100
Total cost of labour (Rs. ha^{-1})	18,800/-
Total cost of labour (Rs. t^{-1})	537/-

(Average of 5 trials)

rhizomes was Rs. 18,800 per ha at wage rates of Rs. 200 and Rs. 120 per day for skilled labour and women labour respectively.

The soils of the experimental location were analysed for their textural composition at the optimum moisture content of about 15.5 per cent (d.b). The percentage clay, sand and silt in the soil samples were 20, 55 and 45 per cent respectively which was classified as typical silty loam soil. The bulk density of the soil at 15.5 per cent (d.b) ranged between 1.5 and 1.6 kg cm^{-2}.The mean values of cone index of the soil was 1.4 Mpa at a soil depth of 20 cm (Table 3).

Table 3. Soil and rhizome parameters under investigation (Variety, BSR - 1)

Parameters	Maximum	Minimum	Mean
Soil parameters			
Moisture content, % d.b.	16.25	15.25	15.50
Bulk density (g cm^{-3})	1.60	1.50	1.55
Cone index at 20 cm depth (Mpa)	1.45	1.35	4.1
Rhizome parameters			
Plant population, per square meter	16	12	13.6
Bulk density (kg m^{-3})	986	968	974.6
Lateral Spread (mm)	270	220	240
Vertical spread (mm)	195	150	165
Weight of turmeric rhizome at the time of harvest with soil (g)	600	530	545
Weight of turmeric rhizome at the time of harvest without soil (g)	260	200	245
Moisture content per cent (d.b) of rhizome at harvest	76.5	72.0	74.1
Mother rhizome, Number of fingers per hill	2.0	2.0	2.0
Primary finger, Number of fingers per hill	10.0	6.0	8.2
Secondary fingers, Number of fingers per hill	18	10	13.1

The crop parameters which could influence the mechanical harvesting of turmeric were identified as plant population, rhizome spread (vertical and lateral), rhizome weight, number of fingers/rhizome, moisture content and bulk density of rhizomes (Table 3). The plant population for the BSR -1 variety of turmeric ranged from 12 to 16 per m^2. The lateral spread was 22 to 27 cm and the vertical spread was 15 to 19 cm. Average rhizome weight was 545 g with soil and 245 g without soil. The moisture content of rhizomes at the time of harvest is an important parameter while digging it out from soil. The moisture content of the rhizomes varied from 72 to 76.5 per cent (d.b). Since the moisture content of rhizomes at the time of harvest was relatively high, the soil has a tendency to adhere to the rhizome and it comes out along with the soil adding to the weight of the crop to be handled by the machine. The bulk density of rhizome which is an important parameter in selecting the conveyer speed varied from 968 to 986 kg m^{-3}. The number of fingers per hill determines the volume of crop to be handled by the machine. The number of fingers per hill varied from 2.0, 8.2 and 13.1with respect to mother rhizome, primary and secondary fingers.

Mechanical harvesting

Effect of rake angle on performance parameters

The maximum depth of cut of 215 mm was observed at 25° rake angle followed by 20° (200 mm). The highest harvesting efficiency of 98.5 per cent was observed at both 25° and 20° rake angle (Table 4). Increased rake angle increased the harvesting efficiency of the crop. This is due to higher depth of cut of the soil at higher rake angle. It is seen that the highest undug turmeric rhizome of 4.2 per cent was recorded at 15° angle. The highest

Table 4. Effect of rake angle on depth of cut, harvesting efficiency, damage to turmeric rhizome, undug turmeric rhizome and draft

Rake angle (°)	Depth of cut (mm)	Harvesting efficiency (%)	Damage (%)	Undug (%)	Draft (N)
15	180	94.5^a	2.0^a	4.2^a	553.2^a
20	200	98.5^b	1.1^b	1.2^b	590.6^b
25	215	98.5^b	0.9^b	1.2^b	629.9^c
CV	2.28	11.7	5.67	6.22	3.91
SE	1.39	0.63	0.18	0.28	0.63
CD (0.05)	2.94	1.28	0.33	0.53	4.95

draft of 629.9 N was recorded at 25° and the least draft of 553.2 N was observed at 15° rake angle.

The maximum harvesting efficiency of 98.5 per cent and minimum damage of 1.2 per cent was recorded at the depth of 20 -21 cm at the rake angles of 20 and 25°, which were on par (Table 4). Hence, 20 deg rake angle was adopted for further experimentation for optimizing the conveyor speed keeping in view the lesser draft at lesser rake angle when compared to 25°. Table 4 shows that the rake angle of 15° had lower draft compared to 20° rake angle. However, 20° was optimized as it yielded less damage (1.1 per cent) and undug turmeric (1.2 per cent) was also less compared to 15° of rake angle (damage 2 per cent and undug 4.2 per cent).

Effect of speed of conveyor on rhizome carried over, soil carried over, and rhizome damaged

The effect different conveyor speeds of 3.0 km/h, 4.5 km/h and 6.0 km/h were evaluated in terms of turmeric rhizome conveyed, soil carried over and rhizome damaged by the power tiller mounted turmeric harvester (Table 5 and Fig. 5). The peripheral velocity of the conveyor is significant, because at lower velocity, the harvested crop may not be carried over the conveyor. If the conveyor-elevator runs at higher velocity, the produce would be thrown resulting in damage of the rhizomes. Many research workers conducted studies at various conveyor speeds in the range of 2.75 to 5 km h^{-1}. In groundnut, the peripheral speed of conveyer was optimized as 2.5 km h^{-1}(Ruiz and Oritz, 1975), 3.75 km h^{-1} (Duraisamy, 1997), 4.25 km h^{-1} (Suryawanshi, 2003) and 5.00 km h^{-1} (Bilanski *et al.*, 1989), based on the design of the equipment. In the case of tractor operated turmeric harvester it was optimized as 4.5 km h^{-1} by Annamalai (2009).

Table 5. Effect of speed of conveyor on rhizome carried over, soil carried over and rhizome damaged

Speed of conveyor (km h^{-1})	Rhizome carried over (%)	Soil carried over (%)	Rhizome damaged (%)
3.0	98.1[a]	5.7[a]	1.6[a]
4.5	98.6[b]	6.2[b]	0.9[b]
6.0	98.9[b]	9.4[c]	3.9[c]
CV	2.21	4.18	4.76
SE	0.20	0.21	0.17
CD (0.05)	0.32	0.40	0.37

It is seen that the highest percentage of turmeric rhizome conveyed (98.9 per cent) was recorded at 6.0 km/h (Table 5). Increase in the conveyor speed had positive impact on the per cent of rhizome carried over. It is also observed that as the conveyor speed increased, the percentage soil carried over also increased. The highest soil carried over was obtained at 6.0 km/h (10%). The highest damage to turmeric rhizome of 3.9 per cent was recorded at 6.0 km/h. The least damage to the conveyed turmeric rhizome of 0.9 per cent was observed at 4.5 km/h.

At the slower conveyor speed of 3.0 km/h, there was accumulation of the soil with rhizomes on conveyor and as result of this, there was clogging of the conveyor system. In due course of the operation, the accumulation of the soil would lead to excess load on the conveyor assembly. At the conveyor speed of 6.0 km/h, the higher speed would damage the rhizomes due to the impact force. The conveying efficiency of 98.8 per cent with minimum soil carried over of 6.0 per cent and minimum rhizome damage of 0.8 per cent was recorded at conveyor at 4.5 km/h speed.

Performance evaluation of power tiller mounted turmeric harvester

The performance data obtained at an average of five trials (Figs. 4 and 5), each of 0.4 ha area at soil moisture of 15.5 per cent (d.b.) is given in Table 6. The labour required for harvesting turmeric using power tiller mounted harvester was 2.5 man-h/ha for operating the equipment and 80 women- h/ha for picking the harvested rhizomes. The effective

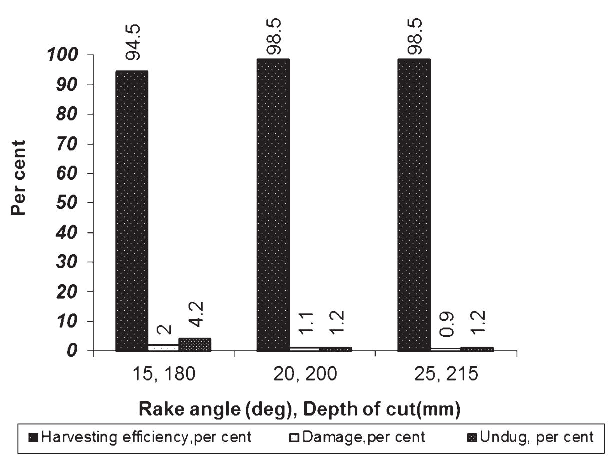


Fig. 4. Effect of rake angle and depth of cut on harvesting efficiency, damage to turmeric rhizome and undug turmeric rhizome

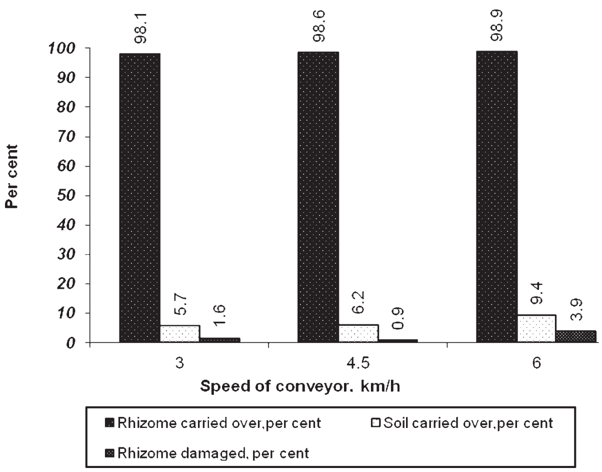


Fig. 5. Effect of speed of conveyor on rhizome carried over, soil carried over, and rhizome damaged

field capacity was found to be 0.08 ha/h. The harvesting efficiency was 98 per cent, with damage caused to the rhizome being 2 per cent, leaving 2 per cent undug rhizome in the soil. The harvesting efficiency of manual labour was about 91.5 per cent (Table 2). This shows that an additional quantity of about 6.5 per cent of the crop which otherwise would have been left undug from soil could be realised as yield and thus the productivity could be considerably improved by mechanical harvesting of turmeric, bringing additional revenue to the farmer. Considering the high price of Rs. 4000 to 5000 per tonne for the fresh rhizome, the additional income that may be generated by reducing the field losses will be considerable.

Cost economics

The cost of harvester was Rs. 50,000/-. The cost economics study showed that the cost of harvesting per hectare was Rs. 7,553/- (Table 6) with the prototype harvester while it was Rs.18,800/- (Table 2) with manual harvesting at wage rate of Rs. 300, Rs. 200 and Rs. 120 per day for power tiller operator, men and women labour, respectively. The saving in cost was 60 per cent by harvesting with mechanical harvester over manual harvesting. The breakeven point was 16 per cent of annual utility and the payback period was 0.5 year for the power tiller mounted turmeric harvester.

Table 6. Performance tests - power tiller mounted turmeric harvester

A)	**Field performance**	
1.	Effective working width (m)	0.5
2.	Effective field capacity (ha h^{-1})	0.08
3.	Field efficiency (%)	81.5
4.	Speed of machine (km h^{-1})	1.2
5.	Fuel consumption (l h^{-1})	1.05
6.	Fuel consumption (l ha^{-1})	15
7.	Rhizomes left undug (%)	2.0
8.	Harvesting efficiency (%)	98.0
9.	Damages (%)	2.0
B)	**Cost economics**	
1.	Fixed cost (Rs. h^{-1})	67.25
2.	Operational cost (Rs. h^{-1})	537.00
3.	Operational cost (Rs. ha^{-1})	7553.00
4.	Harvesting manual method (Rs. ha^{-1})	18,800.00
5.	Savings in cost (Rs. ha^{-1})	11,247.00
6.	Savings in cost (%)	59.82
7.	Breakeven point (% of annual utility)	16.53
8.	Payback period (years)	0.51

(Average of 5 trials)

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