Original Research Article

Determination of Soil Parameters and Pulling Force Requirement of Tapioca Root

ABSTRACT

Aims: This paper aims to explore the soil parameters and pulling force requirement of tapioca root for the design and development of tractor operated tapioca harvester.

Place and Duration of Study: The study was conducted to investigate the soil parameters and pulling force requirement of tapioca roots at farmer's field in the year 2021-22.

Methodology: The soil parameters *viz.* moisture content, bulk density, cone index and shear strength and pulling force requirement of tapioca root were studied using standard test procedure that plays an important role in design of soil engaging components and conveying unit of the tuber harvester.

Results: The results showed that soil moisture content varied from 13.11 to 16.08 *per cent*, whereas bulk density ranged from 1483.07 to 1729.56 $kg\ m^{-3}$. The cone index varied from 0.33 to 0.98 $N\ mm^{-2}$ with an average value of 0.637 $N\ mm^{-2}$ and shear strength ranged from 1.34×10^{-3} to 3.48×10^{-3} $N\ mm^{-2}$ with the mean value of 2.46×10^{-3} $N\ mm^{-2}$. The average value of pulling force requirement for tapioca roots was 103.4 *kgf*. The root depth and root yield per plant of tapioca roots has an average value of 250.30 *mm* and 7.82 *kg*.

Conclusion: The study shows that bulk density of soil increased with increase in soil moisture content and had a linear relationship. The coefficient of determination (R^2) for the regression model was 93.20 *per cent* by revealing the linear relationship between shear strength and cone index. Thus shear strength and cone index are related with each other and have an indefinite effect on the design parameters of soil engaging components of tuber harvester.

Keywords: *Moisture content, pulling force, shear strength, soil parameters, Tapioca.*

1. INTRODUCTION

Agriculture plays a vital role in India's economy. About 54.6 *per cent* of the total workforce is engaged in agricultural and allied sector activities and accounts for 17.1 *per cent* of the country's Gross Value Added (GVA) for the year 2017-18. As per the Land Use Statistics 2014-15, the total geographical area of the country is 328.7 *million hectares*, of which 140.1 *million hectares* is the reported net sown area and 198.4 *million hectares* is the gross cropped area with a cropping intensity of 142 *per cent*. Root and tuber crops, namely potato, tapioca, sweet potato, elephant yam and other minor tuber crops are important to agriculture, food security and income for about 2.2 *billion* people in developing countries. Globally tuber crops are grown in an area of 67 *million ha* with a production of 887 *million tonnes* in 2017 [9]. In India, tapioca and sweet potatoes are the most important tuber crops due to its large area under cultivation and its varied uses. Tapioca (*Manihot esculenta*) is the most important source of calories in the human diet and major carbohydrate food for around 500 *million* people throughout the world.

Globally, Tapioca is grown in an area of 18.51 *million ha* with a production of 276.65 *million tonnes*. India acquires significance in the global tapioca scenario due to its highest productivity of 27.92 *t/ha*. It is cultivated in an area of 0.26 *million ha* in country with a production of 7.2 *million tonnes*. Cassava is mainly cultivated in the southern parts of India, particularly in Kerala and Tamil Nadu, which contributes over 92 *percent* of the total cassava production in the country [10]. Kerala state currently contributes about 31 *per cent* of total production in the country [5].

Tapioca grows well in well-drained laterite, gravelly and sandy loam soils. The main planting seasons are April-May with the onset of southwest monsoon and September-October with the onset of northeast monsoon. Pit, flat, ridge or mound method of planting can be adopted depending upon soil type, topography of land. Tapioca roots are ready to harvest 9-10 months after planting [4]. Harvesting is a major constraint for cultivation of tapioca due to bigger in size and goes deeper into the soil. Manual harvesting is a time-consuming activity, stressful and full of drudgery, especially during the dry season. In designing a machine for digging and separating of tuber, soil parameters *viz.* moisture content, bulk density, cone index and shear strength and pulling force requirement of tapioca root are important parameters [11]. Therefore, a research work was focused on the objective to determine the soil parameters and pulling force requirement of tapioca roots. Moreover, the results from this research will assist in the design of various parts of tractor operated tapioca harvester.

2. MATERIALS AND METHODS

The soil parameters and pulling force requirement which are relevant to the research were studied for tapioca root. The study was carried out at the farmer's field at Kavumpuram panchayat that lies between latitude 10°54' E and longitude 76°3' N. The soil parameters *viz.* moisture content, bulk density, cone index and shear strength and pulling force requirement of tapioca root are important for the design of soil engaging components of tuber harvester [8]. These parameters were determined at the time of harvest using standard test procedure. The methodology used in the study of these parameters was given below.

2.1 Soil Parameters

2.1.1 Moisture content

The soil moisture content may be expressed by weight as the ratio of the mass of water present to the dry weight of the soil sample, or by volume as ratio of volume of water to the total volume of the soil sample [1]. Soil samples were collected at different locations of the fields at depth of 5-30 *cm*. Soil samples of 50 *g* each were collected in different containers and placed in an electric oven for 24 *h* at 105°*C*. The weight before and after drying was found out using an electronic weighing balance having a sensitivity of 0.01*g*.

Soil moisture plays an important role as it affects the draft of implement and slip. The moisture content of the soil sample in per cent dry basis was determined using the formula given in equation 1 [12].

$$MC = \frac{W_i - W_f}{W_f} \times 100 \qquad \ldots\ldots(1)$$

where, *MC* is soil moisture content, *per cent* (dry basis); W_i is initial weight of soil sample (*g*) and W_f is final weight of dry soil sample (*g*).

2.1.2 Bulk density

The compactness of the soil is determined by measuring bulk density. It was conducted by core cutter method. Soil samples were collected randomly in field with the help of core cutter (Fig. 1). Bulk density of soil samples were measured by core cutter having its inner diameter as 10 *cm* and height of the core cutter as 12.5 *cm*. The soil samples were collected at depth level of 5-30 *cm* before operation of digging. The bulk density of soil was determined using the formula given in equation 2 [2].

$$\rho = \frac{M}{V} = \frac{4\,M}{\pi\,D^2\,L} \qquad \ldots\ldots(2)$$

where, ρ is bulk density of soil (g/cm^3), *M* is mass of soil contained in core sample (*g*), *V* is volume of core sampler (cm^3), *D* is diameter of core sampler (*cm*) and *L* is length of core sampler (*cm*).

Fig. 1. Measurement of mass of soil contained in core sample

2.1.3 Cone index

Cone index provides an indication of soil resistance and it is expressed as force per square centimeter required for a cone of standard base area to penetrate into soil to different depths [7]. Cone index for the same soil varies with the cone apex angle, area of cone base and depth of penetration. Cone penetrometer was used to measure the penetration resistance of the soil [6]. It was positioned in the field, uniform force was applied on the handle and deflection of dial gauge was noted for every 5 cm depth (Fig. 2). The cone index was measured for 5, 10, 15, 20, 25 and 30 *cm* depths at different locations of the field to prevent error in the readings and recorded manually.

Fig. 2. Determination of soil cone index

2.1.4 Shear strength

Shear strength of soil is stated as the maximum resistance offered by the soil to shearing stresses. The in-situ measurement of shear strength of soil was carried out using a vane shear test apparatus. Torque applicator was fixed on the stand with the help of spikes. A vane size of 37.5 *mm* diameter was connected to the vane rod and pushed downwards with a moderate steady force up to a depth of 50 *mm* below the bottom of the bore hole. The initial dial gauge reading was set to the zero and gear handle was turned so that the vane can rotate at the rate of 0.1° *per second*, in order to achieve uniform rate of 12 *turns per minute*. Vane was rotated completely ten times to disturb the soil. Torque indicator dial gauge reading was noted at every half minute interval and rotation of vane was continued until the reading drops appreciable from the maximum. The shear strength of soil was determined using the formula given in equation 3 [12].

$$S = \frac{T}{\pi\left(\frac{D^2H}{2}+\frac{D^3}{6}\right)} \qquad \ldots\ldots(3)$$

where, S is shear strength (*kg cm*$^{-2}$), T is torque (*kgf.cm*), D is overall diameter of vane (*cm*) and H is Height of the vane (*cm*).

2.2 Pulling force requirement

The force required for uprooting the tapioca root from soil was determined using a pulling force measuring apparatus (Fig. 3). The setup is composed of a metallic frame on which a shaft with handle was provided. A load cell of 500 *kg* capacity was attached with a rope on one side to the shaft. The tapioca plant stem was tied firmly with a rope and attached to the other side of load cell. The handle is rotated slowly and a steady vertical force is applied to uproot the tapioca root. The reading as indicated by the digital indicator was recorded and the pulling force requirement and agronomic parameters *viz.* root depth and yield per plant were determined for 25 plants selected randomly in the field [3].

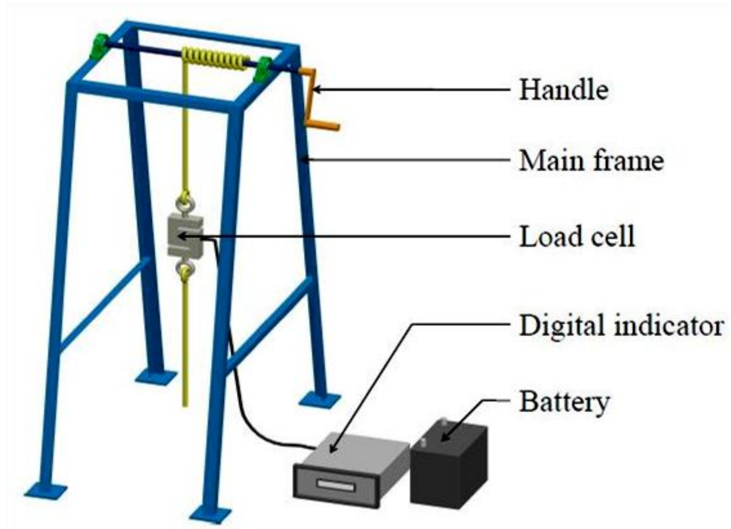

Fig. 3. Pulling force measuring apparatus

3. RESULTS AND DISCUSSION

3.1 Soil Parameters

The soil parameters *viz.* moisture content, bulk density, cone index and shear strength of tapioca root were determined and the results are rationalized below in Table 1.

Table 1. Soil parameters of tapioca root

S.No.	Moisture content (*% d.b.*)	Bulk density (*kg m^{-3}*)	Cone index (*N mm^{-2}*)	Shear strength (10^{-3} × *N mm^{-2}*)
1.	13.59	1483.07	0.327	1.34
2.	14.81	1675.58	0.437	1.56
3.	13.11	1570.66	0.545	2.41
4.	15.99	1639.93	0.676	2.89
5.	16.08	1729.56	0.860	3.07
6.	14.44	1520.75	0.978	3.48
Mean	14.67	1603.26	0.64	2.46
SD	1.22	94.70	0.25	0.86
CV (%)	8.30	5.91	39.21	34.82

The soil moisture content varied from 13.11 to 16.08 *per cent* with mean of 14.67 *per cent*, coefficient of variation of 8.30 *per cent* and standard deviation of 1.22. The machine needs to be designed considering the obtained moisture content of soil as it affects the draft of implement. The bulk density of the soil ranged from 1483.07 to 1729.56 kg m^{-3} with a mean of 1603.26 kg m^{-3}, coefficient of variation of 5.91 *per cent* and standard deviation of 94.70. It was observed that bulk density of soil increased with increase in soil moisture content and had a linear relationship. The power requirement of any soil working tool or machinery is decided by the bulk density of soil.

Fig. 4 shows that the average cone index increases with an increase in the soil depth. The reason behind this is the soil structure becomes more stable with an increase in the soil depth, thereby cone penetration resistance increases. The cone index varied from 0.33 to 0.98 $N\ mm^{-2}$ with an average value of 0.637 $N\ mm^{-2}$, coefficient of variation of 39.22 *per cent* and standard deviation of 0.25. The coefficient of determination (R^2) value was estimated as 99.19 *per cent* indicating the high accountancy of cone index with depth and it is depicted in Figure 4. The model was highly significant ($p \leq 0.05$) which means that there is a linear relationship between cone index and depth and it is reported in Table 2.

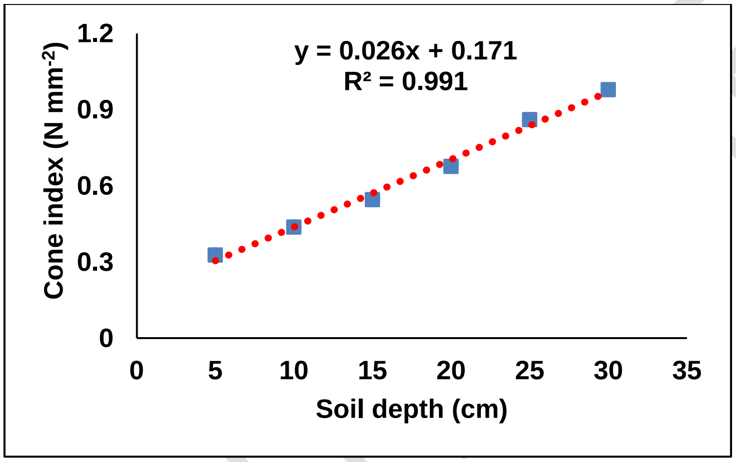

Fig. 4. Relationship between cone index and soil depth

Table 2. ANOVA for Cone index

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.310	0.310	488.004	0.000025
Residual	4	0.003	0.001	-	-
Total	5	0.312	-	-	-

Fig. 5 shows a progressive increase in average shear strength with increase in soil depth. The factor responsible for this increase in shear strength is same as that responsible for cone index i.e., increase in the soil compaction. The shear strength of soil varied from 1.34×10^{-3} to 3.48×10^{-3} $N\ mm^{-2}$ with the mean value of 2.46×10^{-3} $N\ mm^{-2}$. The coefficient of variation was found out as 34.82 *per cent* while the standard deviation was 0.86. Shear strength is a vital parameter in soil-tool interaction design of tuber harvester. The coefficient of determination (R^2) for the regression model was 96.22 *per cent* as given in Figure 5 revealing the linear relationship between shear strength and soil depth. The model was significant as $p \leq 0.05$ and it is shown in Table 3.

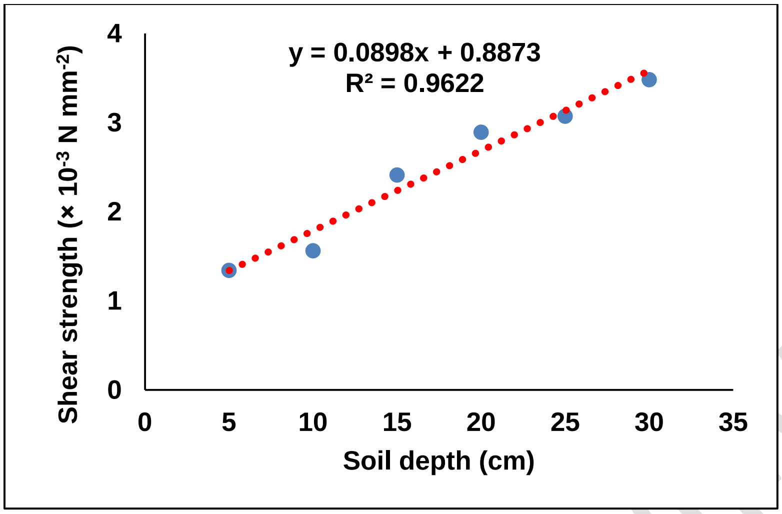

Fig. 5. Relationship between shear strength and soil depth

Table 3. ANOVA for Shear strength

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3.526	3.526	101.820	0.000543
Residual	4	0.139	0.035	-	-
Total	5	3.664	-	-	-

The relation between shear strength and cone index was determined and analysed statistically. The coefficient of determination (R^2) for the regression model was 93.20 *per cent* as given in Fig. 6 revealing the linear relationship between shear strength and cone index. The model was significant as $p \le 0.05$ and it is shown in Table 4. Hence, shear strength and cone index are related with each other and have an indefinite effect on the design parameters of soil engaging components of tuber harvester.

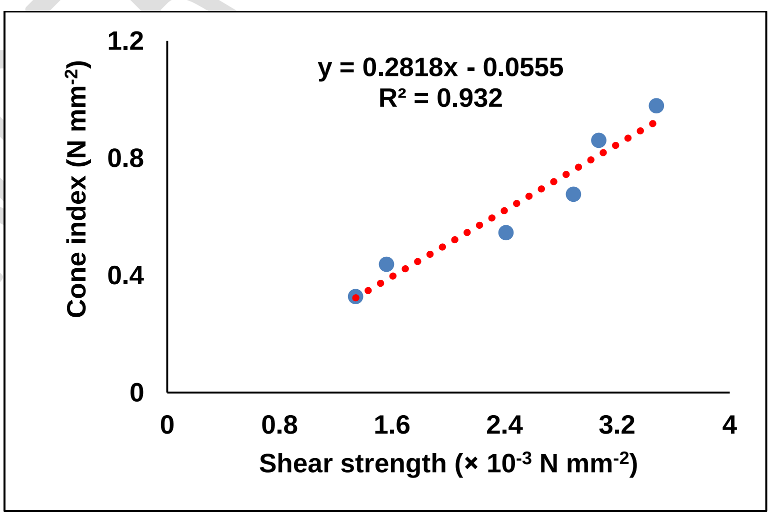

Fig. 6. Relationship between shear strength and cone index

Table 4. ANOVA for Shear strength wit cone index

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.291	0.291	54.866	0.00177
Residual	4	0.021	0.005	-	-
Total	5	0.312	-	-	-

Table 5. Pulling force requirement, root depth and yield per plant of tapioca roots

Replica	Pulling force (*kg*)	Root depth (*mm*)	Root yield (*kg/plant*)
1	96.00	244.80	7.59
2	103.00	251.40	8.16
3	84.00	225.60	6.43
4	89.00	235.00	6.74
5	118.00	263.40	8.39
6	94.00	239.00	7.28
7	101.00	249.20	8.36
8	98.00	247.60	7.62
9	85.00	231.40	6.12
10	106.00	254.00	9.00
11	94.00	241.50	7.34
12	112.00	258.00	6.94
13	110.00	256.40	8.56
14	93.00	237.80	7.13
15	120.00	265.00	8.45
16	86.00	234.30	6.50
17	116.00	260.00	9.12
18	92.00	237.40	7.04
19	120.00	268.50	8.56
20	103.00	251.00	7.92
21	126.00	274.20	9.25
22	98.00	247.00	7.78
23	112.00	258.30	8.50
24	105.00	253.80	7.80
25	124.00	273.00	8.94
Mean	103.4	250.30	7.82
SD	19.80	1.99	0.95
CV (%)	19.15	7.97	12.21

3.2 Pulling force requirement

The data related to pulling force requirement, root depth and yield per plant of tapioca was presented in Table 5. The pulling force requirement of tapioca root is an important parameter in designing the various components of conveying unit in order to achieve effective uprooting and conveying efficiency of tapioca roots. The pulling force requirement for tapioca roots varied from 84 to 126 *kgf* with an average value of 103.4 *kgf*, the maximum pulling force requirement of 126 *kgf* was considered while designing the functional components of tractor operated tapioca harvester. The coefficient of variation was found out as 19.15 *per cent* while the standard deviation was 19.80. The root depth of tapioca roots ranged from 225.60 to 274.20 *mm* with an average value of 250.30 *mm*, coefficient of variation was 7.97 *per cent* and standard deviation was found to be 1.99. The root yield per plant varied from 6.12 to 9.25 *kg* with mean value of 7.82 *kg*, coefficient of variation was 12.21 *per cent* and standard deviation was found to be 0.95.

4. CONCLUSION

In the present research, soil parameters of tapioca roots such moisture content, bulk density, cone index and shear strength and pulling force requirement were studied which influence the design of soil engaging components of tuber harvester. The soil moisture content varied from 13.11 to 16.08 *per cent* with mean of 14.67 *per cent*, coefficient of variation of 8.30 *percent* and standard deviation of 1.22. The study shows that bulk density of soil increased with increase in soil moisture content and had a linear relationship. The cone index varied from 0.33 to 0.98 $N\ mm^{-2}$ with an average value of 0.637 $N\ mm^{-2}$, coefficient of variation of 39.22 *per cent* and standard deviation of 0.25. The average cone index, shear strength of soil increases with an increase in the soil depth as soil structure becomes more stable with an increase in the soil depth. The pulling force requirement for tapioca roots varied from 84 to 126 *kgf* with an average value of 103.4 *kgf*. The root depth and root yield per plant of tapioca roots ranged from 225.60 to 274.20 *mm* with an average value of 250.30 *mm* and 6.12 to 9.25 *kg* with mean value of 7.82 *kg*.

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