Comparative evaluation of manual cassava harvesting techniques in Kerala, India

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Abstract: In India, cassava is consumed as a secondary staple along with the main staple, rice, and many rural poor consume it as the staple in different forms of preparations. Though harvesting is known to be one of the most difficult and cost-intensive field operation in cassava cultivation, mechanisation of cassava harvesting is still very low in most cassava growing areas of India due to topographic constraints, methods and scale of cultivation. The most viable solution to overcome these constraints is to promote the use of more efficient manual harvesting tools. Thus, the main objective of this study was to field evaluate the efficiency of four manual cassava harvesting techniques under different land preparation methods in terms of field capacity, level of drudgery and root tuber damage or breakage. The study also sought to investigate the effect of cassava agronomic parameters on uprooting force requirement. Field study was carried out at the Central Tuber Crops Research Institute (CTCRI) research field (under upland mound method) and at Chenkal village on farmers' fields (under lowland flat method); both in the Kerala state of India. Harvesting was done using the CTCRI lever, prototype harvester, hoe and manual uprooting (control) techniques. Results from the study showed that the use of manual harvesting tools is preferable on relatively dryer soils, whereas manual uprooting technique is best suited for soils with relatively higher moisture contents. However, best efficiency of manual harvesting is achieved when cassava plants are coppiced before harvesting. Also, cassava uprooting force requirement, to a greater extent is influenced by root tuber yield, root depth and number of root tubers per plant, especially under upland mound land preparation method. It is however recommended that a user performance assessment and economic feasibility analysis of the prototype harvester and CTCRI lever be conducted with farmers to facilitate future design modifications, where necessary and to support future adoption. As a design recommendation, the pressure at the fulcrum for both the CTCRI lever and prototype harvester should be reduced to avoid sinking during harvesting in soils with relatively higher moisture contents.

Keywords: cassava, field capacity, drudgery, coppiced, efficiency

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1 Introduction

Cassava (*Manihot esculanta Crantz*) is the world's third most important crop and an essential source of food and income throughout the tropics (IFAD et al., 2008). Worldwide, cassava provides the livelihood for more than 500 million farmers and countless processors and traders (FAO and IFAD, 2001). It is the basic staple food of millions of people in the tropical and subtropical regions, as well as being a major source of raw material such as flour and starch for numerous industrial applications and animal food with worldwide acreage of more than 18 million ha and annual root yield of more than 233 Mt (Anderson et al., 2000; FAOSTAT, 2011). Cassava provides food security, not only because it can be grown on less productive land, but also because it is a source of income for producers and generally a low cost source of food (Plucknett et al., 1998).

According to FAOSTAT (2011), out of a total world cassava production of 233,796,000 t, Africa accounts for 51% followed by Asia with a production of 35%, and the remaining production of 14% going to the Americas.

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Cassava yields in India are by far the highest in the world, however in terms of cassava production in Asia, India comes third with a total production of 9,623,000 t after Indonesia (22,039,000 t) and Thailand (30,088,000 t). The reason for this disparity is due to the high production costs as a result of unavailability or high cost of labour. Consequently, the cost per ton of cassava produced is still fairly high, making it difficult for India to compete on the world market (Howeler, 2012; FAOSTAT, 2011). For the past three decades, India's cassava production has not seen much significant change, however yield continues to increase significantly chiefly due to the use of improved cassava varieties (Howeler, 2012). If this trend continues for the next decade, it is envisaged that labour constraints will be shifted from land preparation to harvesting as is been experienced in most cassava growing regions of Africa.

In Kerala state of India, where currently about 31% of total production is located, practically all cassava is domestically produced and used for human consumption, mostly after boiling or roasting of fresh roots, or in the form of processed products such as sago (tapioca pearls), starch and a variety of snack foods (CTCRI, 2012; Howeler, 2012). Cassava is also an important cash crop, especially in the state of Tamil Nadu where about 61% of total cultivation is located; it is the raw material used for the industrial production of starch and sago and caters to the needs of 1300 starch and sago factories, providing employment to 0.4-0.5 million people (Byju et al., 2010; CTCRI, 2012).

Cassava is ready for harvest as soon as there are storage roots large enough to meet the requirements of the consumer, starting from six-seven months after planting, especially for most of the new cassava cultivars (Ekanayake et al., 1997; USDA and NRCS, 2003). Cassava is mostly harvested by hand, lifting the lower part of stem and pulling the roots out of the ground, then detaching them from the base of the plant by hand after the upper parts of the stem with the leaves are removed. Manual harvesting may also employ harvesting tools such as hoe, cutlass, mattock, earth chisel etc. However, due to the relatively higher level of drudgery, only males are usually involved in manual cassava harvesting activities. According to Nweke et al. (2002), manual harvesting requires about 22-62 man d ha^{-1}. Mechanical harvesting of cassava involves the use of a harvesting implement integrally hitched to a tractor to uproot the cassava roots. Manual effort is however required after the uprooting has been completed to collect and detach the cassava root tubers. However, research on mechanical cassava harvesting in India is yet coming into the limelight.

According to Agbetoye (2003), the most difficult operation in cassava production is harvesting. Research conducted by Addy et al. (2004) also revealed that cassava harvesting constituted the highest production cost. Cassava is a highly perishable crop and begins to deteriorate as early as one to three days after harvest; thus harvesting cassava should be done at the right time and in the proper way (IITA, 2004; Kuiper et al., 2007; USDA and NRCS, 2003). Early harvesting results in low yield and poor eating quality while on the other hand, when the roots are left too long in the soil, the central portion becomes woody and inedible. It also ties the land unnecessarily to one crop whilst exposing the roots to pests (USDA and NRCS, 2003).

India's cassava production is predominantly small-scale covering just about 0.2-0.8 ha in size (Howeler, 2012). Farmers therefore deem it prudent to harvest manually using rudimentary tools like cutlass, hoes, earth chisel etc. since mechanical harvesting though better, is not only cost ineffective but also unavailable to these resource-poor farmers. Moreover, cassava is usually intercropped with other food crops of benefit to the farmer making it difficult to readily mechanise its harvesting. Furthermore, some of these small-scale cassava farms are located at places which are usually inaccessible to tractors due to the nature of slope and terrain, making mechanical cassava harvesting virtually impossible. Thus a farmer in such an area would have no choice but to harvest manually even if mechanical harvesting is affordable. Also, a larger proportion of cassava harvested on small-scale is mostly consumed domestically for varied food preparations. Marketers would reject roots that are broken, damaged, cut or bruised since consumers would mostly buy and keep their cassava for a while before use. The farmer runs at a loss when damage to roots is severe. Cassava root tuber breakage or damage is therefore a major factor to consider in the selection and adoption of any type of harvesting method depending on the end use of the harvested produce. Where cassava root tuber damage or breakage is of concern, manual harvesting is preferred to mechanical harvesting and vice-versa (Amponsah, 2011).

Different methods of land preparation such as mound, flat and ridge and furrow methods could be followed depending upon the type and condition of soil (Ekanayake et al., 1997; CTCRI, 2012). Mound method may be adopted in soils having higher clay content and restricted drainage, whereas the ridge and furrow method may be employed on slopes to prevent soil erosion. Ridge and furrow method of land preparation is suitable for irrigated cassava under Tamil Nadu conditions. The flat method of planting may be used in places where there are good drainage facilities (CTCRI, 2012). Also, studies by Ennin et al. (2009) have shown that planting cassava on ridges had the advantage of higher cassava root yield coupled with better and easier field management and has the potential for mechanization to further decrease drudgery and increase the scale of production of cassava compared to planting on the flat. Currently, there exists no information on the drudgery levels, percentage tuber breakage and field capacities associated with the various manual cassava harvesting techniques. Moreover, there is no information on force requirement for manual harvesting under different soil conditions and cassava varieties. Such information will be useful to engineers in the design of appropriate harvesting tools and implements in the future.

1.1 Objective of the study

The main objective of this study was to field evaluate the efficiency of four manual cassava harvesting techniques under different land preparation methods.

Specifically, the study sought to:

1) Investigate the effect of cassava agronomic properties on harvesting force requirement for two cassava varieties on different land preparation methods.

2) Assess the level of drudgery, degree of root tuber breakage and field capacity associated with different manual cassava harvesting techniques under upland mound and lowland flat methods of land preparation.

3) Make recommendations to aid necessary future modifications to existing harvesting levers in order to minimise drudgery and increase harvesting efficiency.

2 Materials and methods

2.1 Study area

The study was carried out at the Central Tuber Crops Research Institute (CTCRI) research field and at Chenkal village on farmers' fields; both in the Kerala state of India. Soils at CTCRI (latitude: 8° 32" N; longitude: 76° 65" E, altitude: 50 m above sea level) fall under the soil order Ultisols and Trivandrum series (Soil Survey Organisation, 2007), with a predominantly sandy clay texture. The site experiences a typical humid tropical climate. The mean annual rainfall was 1985 mm, maximum and minimum temperatures were 31.35°C and 24.50°C respectively and the relative humidity was 80%. The soils of the village Chenkal (latitude: 8° 21" N; longitude: 77° 07" E; altitude: 20 m above sea level) fall under the soil order Entisols and the Amaravila series of Thiruvananthapuram district, Kerala, India. (Soil Survey Organisation, 2007). The soil at the experimental site was clay loam in texture. The climate of the study site is humid tropical with mean annual temperature of 27°C and average annual rainfall of 1,767 mm.

2.2 Experimental details

A split plot design with three replicates was used for this study. The main plot treatments were the two land preparation methods; the upland mound and lowland flat, whereas the subplot treatments were the four cassava harvesting tools/techniques; CTCRI lever, harvesting aid prototype, hoe and manual uprooting (control).

2.3 Cassava varieties and land preparation methods

Manual harvesting trials were conducted at nine months after planting (MAP) for both the Cassava Mosaic Resistant (CMR) and "*Ullichuvala*" cassava varieties at the CTCRI and Chenkal village study sites respectively. Cassava was planted on upland mounds at the CTCRI cassava research fields and on lowland flat method at Chenkal farmer's field. Mounds were 0.3 cm high with 0.9 m × 0.9 m spacing. The lowland flat method was practised on 6 m × 3 m and 0.6 m high beds separated by a 0.5 m wide furrow.

2.4 Manual cassava harvesting tools and techniques

Cassava is mostly harvested by hand, lifting the lower part of stem and pulling the roots out of the ground, then detaching them from the base of the plant by hand after the upper parts of the stem with the leaves are removed. The use of manual harvesting tools helps in loosening or reducing the soil forces on the cassava root tubers in order to make it easier to uproot them. For this study, three manual harvesting aids were used; CTCRI harvesting lever (Figure 1), harvesting aid prototype (Figure 2) and a hoe (locally referred to as "*manvetti*") as shown in Figure 3. Manually uprooting the roots without any harvesting tool (Figure 4) was used as the control technique.


Figure 1 Harvesting with CTCRI lever


Figure 2 Harvesting with prototype harvester


Figure 3 Harvesting with a hoe (*manvetti*)


Figure 4 Manual uprooting of cassava

In the Kerala state of India, the hoe is the common tool used for harvesting in all cassava growing areas. The harvesting aid prototype was constructed with the idea of reducing the drudgery of farmers due to waist bending associated with the other harvesting tools which usually lead to waist pains and other bodily weaknesses. The original design was adopted from the International Institute of Tropical Agriculture (IITA) in Nigeria. Several modifications have since been made to overcome some of its design constraints (Amponsah, 2011). The harvesting aid prototype operates according to the 'grip and lift' principle. It consists of a frame to which an immovable griping jaw is attached and a chisel tip which serves as the base for lifting cassava from the soil. The chisel tip can also be used to dig out cassava roots especially in hard and dry soils, where the grip and lift principle becomes difficult to employ due to the tendency of high root tuber damage or breakage.

The CTCRI manual cassava harvester was designed and fabricated at the Central Tuber Crops Research Institute, Kerala with the objective of reducing drudgery involved in manual cassava harvesting. It operates on the second order lever principle. The height of the fulcrum at the far end of the lever can be adjusted which facilitates uprooting of cassava plants raised on flat bed as well as on mounds or ridges. A self-tightening mechanism is used to grip the cassava stem. It has a mechanical advantage of 3.4 and the total weight is 8 kg.

2.5 Data collection

- **Soil Sampling**

Three replicates of soil samples at harvest were randomly taken for soil moisture content and bulk density determination at depths of 0-10, 10-20, 20-30 and 30-40 cm using a 5 cm diameter soil core sampler and a mallet. Soil samples were oven dried at a temperature of 105˚C for 24 h in for soil moisture determination (DeAngelis, 2007).

Additionally, composite soil samples were also taken and analysed to determine their textural classes based on their sand (%), silt (%) and clay (%) content.

Penetrometer tests using an Eijkelkamp penetrologger (Figure 5) were carried out on-site at depths of 0-10, 10-20, 20-30 and 30-40 cm at harvest to determine the soil penetration resistances.

Figure 5 Eijkelkamp penetrologger

• Harvesting force requirement

The force required for uprooting each cassava variety on the different seedbeds under varied soil conditions was determined using a force measuring apparatus (Figure 6) for 50 plants.

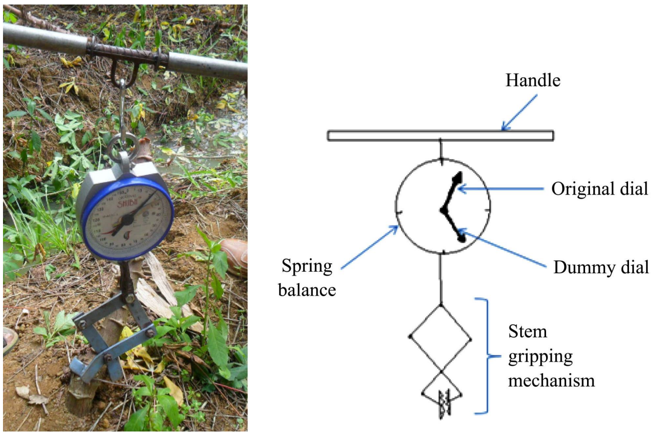

Figure 6 Cassava uprooting force measurement apparatus

The setup has a metallic handle to which a modified spring balance is attached to take weight readings during cassava uprooting in kilograms. Modification of the spring balance was done by attaching a dummy dial beneath the original one. The idea is that the original dial comes back to zero at no load, thus there is the need to have a secondary (dummy) dial which will be dependent on the movement of the primary dial to assist in getting the right reading even after load is taken off the spring balance. However, the dummy dial was always reset to zero before each loading of the spring balance was done. The stem gripping mechanism is firmly attached to the cassava stem and with the help of the handle, a steady vertical force is applied to uproot the cassava. The reading as indicated by the dummy dial is then recorded after the uprooting process is ended.

• Agronomic parameters

Agronomic parameters including stem girth (cm), maximum root diameter (cm) maximum root length (cm), maximum root depth (cm), number of root tubers and root spread (degrees) were determined at harvest for 50 plants each. Root spread was taken using a protractor with reference to the soil surface from both sides of the plant (Figure 7); stem girth and maximum root diameter were measured using a digital vernier caliper, whereas maximum root length and depth were taken using a tape measure. Cassava root tuber yield and damaged (broken) root tubers after harvest were determined using an electronic balance.

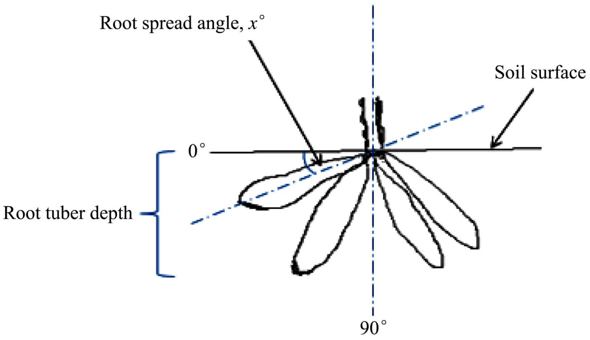

Figure 7 Root orientation measurement

• Drudgery measurements

Polar heart rate sensing device (RS 800 CX) was used to obtain the heart rate for each person during manual harvesting. The Polar heart rate sensor is an instrument that measures the heart beat rate during every physical activity. It has a strap that is worn around the chest area and a watch (monitor) with a sensor which reads the heart rate and logs it per pre-determined interval in seconds. Data stored was downloaded onto a computer for analysis.

Figure 8 shows the Polar heart rate (RS 800 CX) watch and how the chest strap (with heart beat sensor) should be worn before an activity.

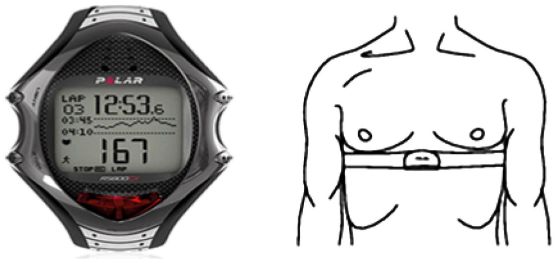

Figure 8 The Polar (RS 800 CX) watch and chest strap as worn by a person

Before and after any field activity, the person was allowed ten minutes period of rest so the heart rate could be stabilized which are referred to as the rest and recovery periods respectively. Figure 9 shows a typical heart rate profile for a person before, during and after a physical activity recorded using the Polar heart rate watch and sensor (RS 800 CX).

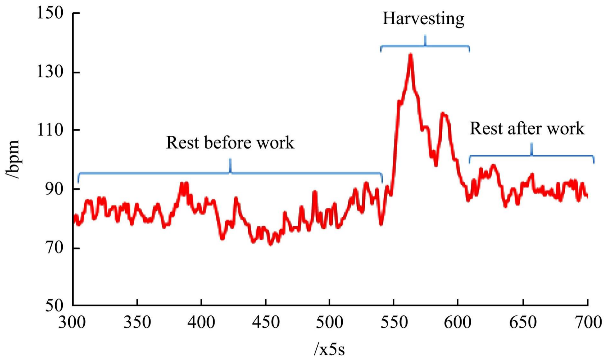

Figure 9 Typical heart rate profile before, during and after a physical activity

The period between the rest and recovery is the work period. This instrument can also calculate how much calories are burnt during any physical activity. This gives an idea of the amount of energy used or the drudgery involved in carrying out any physical work. Knowledge on the amount of energy is used for carrying out a particular physical work is useful in determining the rest period (min/h) required by a person after work using Equation (1), according to Jones et al. (1988).

$$Tr = 60 \times \left(1 - \frac{250}{P}\right) \tag{1}$$

where, Tr = Total rest period, min h^{-1}; P = Gross energy consumption, W.

Using the mean heart rate obtained for a particular field activity to trace for a corresponding energy consumption value on the heart rate - energy conversion chart (Jones et al., 1988), the Gross energy consumption (W) was determined.

- **Field Capacity**

Manual harvesting will be carried out using the various manual harvesting tools after the plants have been coppiced to a level of about 20-30 cm. Three field workers were then tasked to uproot ten cassava plants each on each land preparation method using the various harvesting technique one at a time. Using a stop clock, the time (seconds) taken to harvest the 10 plants was recorded. The capacity (timeliness of operation) for each field worker during harvesting (man-hours/ha) was determined using Equation (2).

$$T = \frac{10000 \times t}{n \times 3600} \ (\text{man-h ha}^{-1}) \tag{2}$$

where, T = Total harvesting capacity, man-h ha^{-1}; t = Total time spent in harvesting, s; n = Number of plants harvested.

- **Root Tuber Breakage**

The percentage root tuber breakage associated with each cassava variety and seedbed preparation was calculated using Equation (3).

$$\text{Percentage Breakage} = \frac{\text{Mass of broken or damaged roots (kg)}}{\text{Total root yield (kg)}} \times 100 \tag{3}$$

2.6 Statistical analysis

The results of harvesting trials and field measurements were statistically analysed as a split plot layout in randomized complete block design (RCBD), using GenStat Discovery Edition 3 (VSN International, 2011). The least significant difference (LSD) was used at the $p<0.05$ level of probability to test difference between treatment means. Analysis of variance (ANOVA) was performed to determine the effects of land preparation method and/or harvesting tools/techniques and their interaction.

3 Results and discussion

3.1 Soil mechanical properties

Figures 10 (a), (b) and (c) respectively present the mean soil moisture content, soil bulk density and penetration resistance versus soil depth at harvest for both study sites.

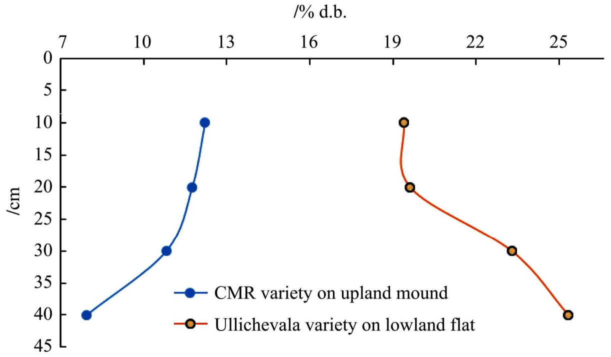

Figure 10(a) Mean soil moisture vs depth

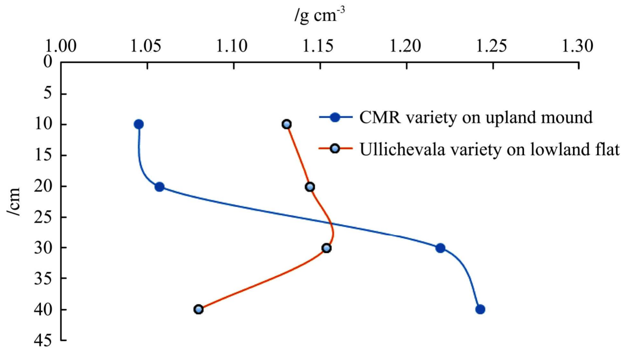

Figure 10(b) Mean soil bulk density vs depth

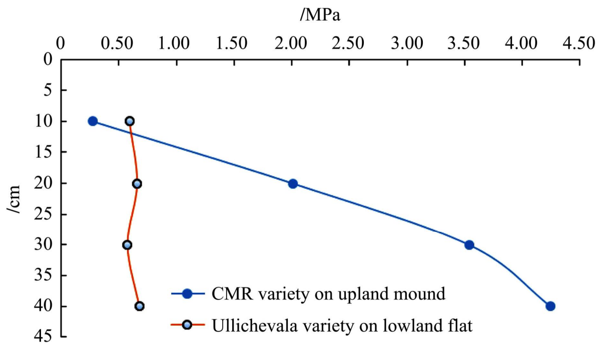

Figure 10(c) Mean soil penetration resistance vs depth

Table 1 shows the statistical differences in soil physical properties (moisture content, bulk density and penetration resistance) between upland mound and lowland flat land preparation methods at 5% level of significance.

Table 1 Differences in soil physical properties under the two methods

Land preparation method	Soil moisture content/% d.b.	Soil bulk density /mg m^{-3}	Soil penetration resistance/MPa
Upland mound	10.68^{b}	1.14^{a}	2.52^{a}
Lowland flat	21.90^{a}	1.13^{a}	0.62^{b}
LSD*	1.23	ns	0.43

Note: *Least significant difference at 5% level.

Figure 10(a) depicts a decreasing soil moisture with increasing depth for CMR variety on upland mound landform, whilst *Ullichuvala* variety on lowland flat depicts an increasing soil moisture with increasing soil depth. At harvest, soil moisture ranged from 7.95%-12.22% d.b. for CMR variety on upland mound and 19.38%-25.32% d.b. for *Ullichuvala* variety on lowland mound at increasing soil depth of 0-40 cm. The statistical disparity (p<0.05) in soil moisture between the two study sites (Table 1) is due to differences in soil type and land preparation methods. Upland mounds usually have relatively lower soil moisture compared to lowland flat systems, which are mostly waterlogged. This explains the trend as depicted by Figure 10(a); mounds are prepared with the aim of conserving enough water for plant growth as well as for proper penetration of roots, whilst flat beds are used in lowlands, since the soil is deep and loose as well as to drain soil moisture to allow for optimal cultivation (CTCRI, 2012).

Figure 10(b) depicts a general increase in soil bulk density with increasing soil depth for CMR variety on upland mound whilst *Ullichuvala* variety showed a decreasing soil bulk density with increasing soil depth. At harvest, soil bulk density ranged from 1.04-1.24 mg m^{-3} for CMR variety on upland mound and 1.08-1.15 mg m^{-3} for *Ullichuvala* variety on flat method at increasing depth of 0-40 cm. This trend in bulk density as shown in Figure 10(b) for both land preparation methods could be attributed to their respective soil textural differences, since bulk density is influenced by soil texture (Pravin et al., 2013). However, from Table 1, there was no significant difference (p<0.05) in soil bulk density between the two landforms.

Graph in Figure 10(c) shows an increasing soil penetration resistance with increasing depth for CMR variety on upland mound whilst *Ullichuvala* variety on lowland flat depicts a generally constant soil penetration resistance with increasing soil depth. Soil penetration resistance at harvest ranged from 0.27-4.25 MPa for CMR variety on upland mound and 0.58-0.68 MPa for *Ullichuvala* variety on lowland flat landform at soil depth of 0-40 cm. The statistical difference (p<0.05) observed for both landforms in Table 1 could be best attributed to the differences in soil moisture content, since soil strength is highly influenced by soil moisture (Utset and Cid, 2001).

3.2 Harvesting force requirement versus agronomic parameters

Table 2 and Table 3 respectively show the correlation matrix on pre-harvesting and agronomic parameters of CMR cassava variety on upland mound and *Ullichuvala* cassava variety on lowland flat landforms at harvest.

From Table 2, the harvesting force requirement for CMR cassava variety on upland mound landform was significantly and positively correlated with root diameter (*r* = 0.32), root depth (*r* = 0. 34), yield per plant (*r* = 0.80) and number of root tubers (*r* = 0.66). There was a significant positive correlation between stem girth and root length with correlation coefficient, *r* = 0.40. Root diameter showed significant positive correlation with yield per plant (*r* = 0.32). A significantly positive correlation was observed for root depth with root length and yield per plant. Root length showed significant positive correlation with yield per plant (*r* = 0.47). There was a strong positive correlation between yield per plant and number of root tubers (*r* = 0.76). It therefore could be deduced that an increase in root diameter, root depth, root tuber yield or number of root tubers would result in a corresponding increase in uprooting force requirement for CMR variety on upland mounds as expected. Also, as expected, increased number of root tubers resulted in increasing root tuber yield. These observations agree with what was reported by Sheriff and Kurup (1992).

Table 2 Correlation matrix on force requirement and agronomic parameters of CMR cassava variety at 9 MAP on upland mound landform

Variables	1	2	3	4	5	6	7	8	9
1. Force requirement	-								
2. Stem girth	0.14	-							
3. Root diameter	0.32*	0.19	-						
4. Root spread (left)	0.11	0.20	-0.03	-					
5. Root spread (right)	0.22	0.12	0.12	0.12	-				
6. Root depth	0.34*	0.21	0.12	-0.07	0.01	-			
7. Root length	0.24	0.40*	-0.08	0.07	0.17	0.64*	-		
8. Yield per plant	0.80*	0.23	0.31*	0.05	0.26	0.56*	0.47*	-	
9. No. of root tubers	0.66*	0.16	0.20	0.13	0.22	0.25	0.13	0.76*	-
Mean	68.11	3.57	9.28	54.48	53.54	32.42	40.74	5.33	3.78
Max	160	6.29	14.11	90	90	44.00	66.00	12	9
Min	16	2.14	6.71	0	0	20.00	22.00	1.00	1.00
StDev	33.10	0.86	1.37	17.10	19.66	5.98	10.36	2.64	1.60
CV (%)	48.60	24.09	14.76	31.39	36.72	18.44	25.43	49.53	42.33

Note: *Correlation significant at 0.05 probability level.

Table 3 Correlation matrix on force requirement and agronomic parameters of *Ullichuvala* cassava variety at 9 MAP on lowland flat landform

Variables	1	2	3	4	5	6	7	8	9
1. Force requirement	-								
2. Stem girth	0.03	-							
3. Root diameter	0.05	-0.19	-						
4. Root spread (left)	-0.20	0.09	0.13	-					
5. Root spread (right)	-0.17	-0.20	0.11	0.09	-				
6. Root depth	0.03	-0.02	0.20	-0.08	0.16	-			
7. Root length	0.11	0.29*	-0.03	-0.08	-0.29*	0.10	-		
8. Yield per plant	0.11	0.15	0.15	0.10	0.01	0.00	0.19	-	
9. No. of root tubers	0.21	0.02	0.03	-0.04	-0.11	0.20	0.21	0.01	-
Mean	88.70	5.61	6.29	51.58	47.18	30.48	37.28	6.78	8.90
Max	150	7.73	8.83	87	90	42	56	11.8	13
Min	30	3.11	3.06	0	0	13.00	21.00	1.50	4.00
StDev	37.79	1.44	1.74	25.40	25.40	6.46	10.26	3.04	2.60
CV (%)	42.60	25.67	27.66	49.24	53.84	21.19	27.52	44.84	29.21

Note: *Correlation significant at 0.05 probability level.

From Table 3, however, significant and positive correlation was only observed between stem girth and root length (r = 0.29) whilst a significantly negative correlation was observed for root spread (right) with root length (r = - 0.29). Though very unexpected, it could be deduced that uprooting force requirement for *Ullichuvala* variety on lowland flat land preparation method was not significantly ($p<0.05$) affected by any of the agronomic parameters at harvest, unlike the CMR cassava variety on upland mound method. However, for both CMR cassava variety on upland mound method and *Ullichuvala* variety on lowland flat method, an increase in stem girth resulted in an increase in root length.

3.3 Manual harvesting evaluation

• Field capacity

Table 4 presents the mean field capacity (man-h ha^{-1}) as observed at harvest for both cassava varieties on respective land preparation methods using the different harvesting techniques for both coppiced and uncoppiced cassava plants.

Table 4 Field capacity (man-h ha^{-1}) at harvest for CMR variety on upland mound and *Ullichuvala* variety on lowland flat method using CTCRI lever, prototype harvester, hoe and manual lifting techniques for both coppiced and uncoppiced cassava plants**

Harvesting technique	CMR variety on upland mound method	*Ullichuvala* variety on lowland flat method
CTCRI lever uncoppiced	43.50^{b}	42.62^{b}
CTCRI lever coppiced	35.02^{b}	40.32^{b}
Prototype harvester uncoppiced	17.73^{b}	40.28^{b}
Prototype harvester coppiced	15.72^{b}	35.37^{b}
Hoe uncoppiced	45.51^{a}	51.32^{a*}
Hoe coppiced	41.92^{b}	48.03^{a}
Manual lifting uncoppiced	47.20^{a*}	37.34^{b}
Manual lifting coppiced	22.71^{b}	30.19^{b}

Note: * Values followed by the same letter in the same group are not significantly different at $p<0.05$; ** Assuming 4 working hours per day, excluding rest periods.

From results in Table 4, it could be seen that for CMR variety on upland mound method, manual lifting of uncoppiced cassava plants recorded the highest significant ($p<0.05$) field capacity of 47.20 man-h ha^{-1} whilst the least (15.72 man-h ha^{-1}) was recorded using the prototype harvester for harvesting coppiced cassava plants. On the other hand, for the *Ullichuvala* variety on lowland flat landform, harvesting coppiced cassava plants with the hoe produced the highest significant ($p<0.05$) field capacity of 51.32 man-h ha^{-1} as compared to manual lifting of coppiced cassava plants, which recorded the least value of 30.19 man-h ha^{-1}. Incidentally, for CMR variety on upland mound method, except for CTCRI lever and prototype harvester, harvesting coppiced cassava plants with the other techniques (i.e. hoe and manual lifting) recorded significantly ($p<0.05$) lower field capacities compared to harvesting uncoppiced cassava plants.

For *Ullichuvala* variety on lowland flat method however, there was no significant difference in field capacities between harvesting coppiced and uncoppiced cassava plants using all four harvesting techniques. Generally, harvesting with a hoe requires great care in order not to injure or cut the cassava root tubers in an effort to scrap off the soil to facilitate easier lifting of cassava roots. And this could be the reason why it required a significantly longer period of time to harvest with the hoe as compared to the other techniques, especially under *Ullichuvala* lowland flat landform conditions.

• Heart rate and drudgery

Table 5 presents the mean heart rate with corresponding gross energy consumption and rest period at harvest for both cassava varieties on respective land preparation methods using the different harvesting techniques.

Table 5 Mean heart rate (bpm) with corresponding gross energy consumption (W) and rest period (min h^{-1}) at harvest for CMR variety on upland mound and *Ullichuvala* variety on lowland landform using CTCRI lever, prototype harvester, hoe and manual lifting techniques

Harvesting technique and land preparation method	Mean harvesting heart rate/bpm	Gross energy consumption/W	Rest period /min h^{-1}
CTCRI lever upland mound	102.12	547	32.58
CTCRI lever lowland flat	110.22	639.28	36.54
Prototype harvester upland mound	100.63	526.46	31.51
Prototype harvester lowland flat	112.36	662.16	37.35
Hoe upland mound	104.11	570.56	33.71
Hoe lowland flat	119.15	741.01	39.76
Manual lifting upland mound	116.73	710.89	38.9
Manual lifting lowland flat	109.2	627.55	36.1
LSD	ns	-	-

It could be deduced from Table 5 that harvesting *Ullichuvala* variety with a hoe on lowland flat landform recorded the highest harvesting heart rate of 119.15 bpm corresponding to an energy consumption of 741.01 W and a rest period of 39.76 min h^{-1}, whilst harvesting CMR variety with the prototype harvester on upland mound method recorded the least harvesting heart rate of 100.63 bpm giving a corresponding energy consumption of 526.46 W and rest period of 31.51 min h^{-1}. However, there was no significant difference (p<0.05) in harvesting heart rate between harvesting techniques and land preparation method, irrespective of cassava variety. It is also worth noting that mean heart rate, gross energy consumption and rest period are directly proportional; the higher the heart rate, the higher the gross energy consumption, leading to longer period of rest to compensate for the used or lost energy. This relationship between energy consumption and rest period agrees with what was reported by Crouter et al. (2004), Freedson and Miller (2000) and Ericsson et al. (2006).

- **Root tuber breakage**

Table 6 presents the mean root tuber breakage (%) observed at harvest for both cassava varieties on respective methods of land preparation using the different harvesting techniques for both coppiced and uncoppiced cassava plants.

Table 6 Percentage root tuber breakage at harvest for CMR variety on upland mound and *Ullichuvala* variety on lowland flat method using CTCRI lever, prototype harvester, hoe and manual lifting techniques for both coppiced and uncoppiced cassava plants

Harvesting technique	CMR variety on upland mound method	*Ullichuvala* variety on lowland flat method
CTCRI lever uncoppiced	5.83^{a}	8.62^{b}
CTCRI lever coppiced	2.02^{b}	5.09^{b}
Prototype harvester uncoppiced	2.65^{b}	8.61^{b}
Prototype harvester coppiced	2.14^{b}	5.88^{b}
Hoe uncoppiced	7.25^{a*}	10.62^{a*}
Hoe coppiced	6.16^{a}	8.26^{b}
Manual lifting uncoppiced	6.79^{a}	6.17^{b}
Manual lifting coppiced	3.58^{b}	2.13^{b}

Note: * Values followed by the same letter in the same group are not significantly different at p<0.05.

From results in Table 6, it could be deduced that for CMR variety on upland mound landform, harvesting with the hoe on uncoppiced cassava plants produced the highest significant (p<0.05) percentage root tuber breakage of 7.25, whilst harvesting with the CTCRI lever on coppiced cassava plants recorded the least significant (p<0.05) value of 2.02. Interestingly, harvesting *Ullichuvala* variety on lowland flat landform using the hoe on uncoppiced cassava plants gave the highest significant (p<0.05) root tuber breakage of 10.62% as compared to manual lifting on coppiced cassava plants, which recorded the least significant (p<0.05) root tuber breakage of 2.13%. It was worth noting that for manual lifting and harvesting with the CTCRI lever for CMR variety on upland flat, percentage root tuber breakage was significantly (p<0.05) lower on coppiced compared to uncoppiced cassava plants. However, for the *Ullichuvala* variety on lowland flat landform, significance difference (p<0.05) between coppiced and uncoppiced was observed only for hoe harvesting technique.

Generally, harvesting CMR variety on upland mounds gave a much lower percentage root tuber breakage compared to harvesting *Ullichuvala* variety on lowland flat landform. This could greatly be attributed to differences in cassava root orientation and plant physiology. However, for soils with relatively higher moisture contents as was experienced on the lowland flat landform, manual harvesting technique is recommended as compared to using any of the harvesting tools, if breakage or damage is of concern. This is because the fulcrum point of both the CTCRI lever and prototype harvesters tend to sink into the soil during harvesting, affecting optimal harvesting efficiency; hence the breakage recorded. Harvesting with the hoe recorded the highest percentage root tuber breakage due to the fact that in an effort to scrap off soil and make it easier to lift the cassava roots, small cuts are made on the roots by the blade tip, which later becomes points of failure or breakage during root lifting from the soil.

4 Conclusions and recommendations

Under upland mound method of land preparation, the prototype harvester recorded the least mean harvesting capacity (16.73 man-h ha^{-1}) whereas the use of hoe recorded the highest (43.72 man-h ha^{-1}). Timeliness of manual harvesting under lowland flat method was generally higher as compared to upland mound method; however, under lowland flat method, manual harvesting technique was the best in terms of timeliness of harvesting.

Gross energy consumption during harvesting ranged from 527 W for the prototype harvester under upland mound landform conditions to 741 W for the hoe under lowland flat landform conditions. However, in terms of level of drudgery during harvesting, there was no significant difference between harvesting techniques and landforms, irrespective of the cassava variety. Cassava root tuber breakage ranged from 2.02% for the CTCRI lever under upland mound landform conditions on coppiced plants to 10.62% for hoe under lowland flat landform conditions on uncoppiced plants.

Cassava uprooting force requirement, to a greater extent is affected by root tuber yield, root depth, root diameter and number of root tubers per plant, especially under upland mound conditions. The use of manual harvesting tools is preferable on relatively dryer (hard) soils, whereas manual uprooting technique is best suited for soils with relatively higher moisture content. However, best efficiency of manual harvesting is achieved when cassava plants are coppiced before harvesting.

It is however recommended that a user performance assessment and economic feasibility analysis of the prototype harvester and CTCRI lever be conducted with farmers to facilitate future design modifications, where necessary and to promote future adoption. Also, there's the need to further field evaluate both the prototype harvester and CTCRI harvesters through a wide range of soil conditions and on different cassava varieties. Such future research should also focus on assessing the effect of upper cassava biomass or harvest index on cassava root tuber breakage during manual harvesting. It is advised that for best manual harvesting efficiency with the prototype harvester and CTCRI lever, farmers should prune their cassava to two stems per plant after crop establishment to facilitate easy gripping. As a design recommendation, there's the need to reduce the pressure at the fulcrum for both the CTCRI lever and harvester prototype to avoid sinking during harvesting in soils with relatively higher moisture contents.

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