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DEVELOPMENT OF A MANUALLY OPERATED CASSAVA HARVESTER USING HYDRAULIC MEDIUM

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ABSTRACT

Cassava harvesting in Nigeria is still a major challenge to many small scale farmers who utilize basic tools and implements in its cultivation. Manual cassava harvesting is difficult and full of drudgery especially during the dry seasons when the soil moisture content is low. The mechanized alternatives are way beyond the reach of resource poor farmers. This research study developed a low cost manually powered harvesting device using a hydraulic ram and plunger system. The major components of the harvester include the base frame, the support stand, lifting arm, lifting medium and the clamp. Some of the design considerations include ease of reproducibility and ability to lift the cassava with minimal damage. The hydraulic power source capable of lifting 5ton of weight was adopted with a human effort of 50N (5 kg). Preliminary evaluation of the device on 20 stands of randomly selected mature cassava stands at 63% soil moisture content recorded a minimum time of 13 seconds and a maximum time of 35 seconds respectively while there was no damage recorded on the tubers and stem girth during the harvsesting procedure as the gradually applied load enusred minimal disturbance was casued to the soil.

Keywords: *Hydraulic medium, Cassava harvester, manual power,*

INTRODUCTION

Cassava is the third largest source of food carbohydrates in the tropics, after rice and maize (FAO, 2001). As a major staple food in the developing world, it provides a basic diet for over half a billion people. It is also one of the most drought-tolerant crops, capable of growing on marginal soils (FAO, 1991). Nigeria is currently the largest producer of cassava in the world with an annual output of over 34 million tonnes of tuberous roots (FAO, 2005) and its production has witnessed consistent increase in output as a result of improved varieties and better production practices.

In Nigeria, cassava production is well-developed as an organized agricultural crop. It has well-established multiplication and processing techniques for food products and cattle feed (IFAD/FAO, 2004). Cassava is produced largely by small-scale farmers using rudimentary implements. The average land-holding is less than two hectares and for most farmers; land and family labour remain the essential inputs (FAO, 2005). Of all the unit processes involved in the production of cassava, harvesting is a major constraint faced by many farmers and one which hinders commercialization efforts. Cassava harvesting, though very crucial, is regarded as one of the major challenges of cassava production, especially during the dry season when soil moisture is at lower levels (IITA, 1997; Anonymous, 2015). All these contribute in making cassava production unattractive to the youth and consequently dependent on aging farmers, who produce limited output (Anonymous, 2015).

Manual cassava harvesting is usually done 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 (Amposah *et al.,* 2017). Additionally, a hoe, chisel, cutlass or mattock may be employed to dig round the standing stem for pulling out the root before detaching the uprooted roots from the base of the plant (Agbetoye, 2003). Manual cassava harvesting is a time-consuming activity, stressful and full of drudgery, especially during the dry season when soil moisture is at lower levels (IITA, 1997; Anonymous, 2015). All these contribute in making cassava production unattractive to the youth and consequently dependent on aging farmers, who produce limited output (Anonymous, 2015).

The research of Ogunjimi *et al.,* (2016), further noted that manual harvesting of cassava tuber does not commensurate with the rapidly expanding cassava processing factories in Nigeria, which was leading to under-utilization of their capacities. Hence, the mechanization of cassava harvesting was paramount to achieving a profitable value chain of cassava processing. Mechanized harvesting which involves the attachment of a harvesting device to the tractor is usually viable only when an entire crop is harvested at one time especially root and tuber crops (FAO, 1989). It is expected that the field be clear of rocks, stumps and other obstacles which impede smooth operation. When mixed with other crops, substantial losses of valuable crops could easily be recorded by the harvesting attachment and the traffic of the agricultural tractor. Most staple roots and tubers that grow beneath the soil are likely to suffer mechanical injury at harvest because of digging tools, which may be wooden sticks, machetes (or cutlasses, hoes or forks (FAO, 1989). Even where available, the cost of utilizing a mechanized cassava harvester is usually beyond the reach of the poor small scale farmers who depend on their harvests for food and income.

Several attempts have been made to augment or out rightly replace the human lifting during cassava harvesting. The International Institute of Tropical Agriculture (IITA) in Nigeria designed and produced a manually operated cassava root tuber lifter for use by small scale farmers for cassava growing areas in Africa(Amposah, 2011). The downside to this solution was the attendant drudgery that comes with its use over time as significant human effort was required for its lifting operation. The National Centre for Agricultural Mechanization (NCAM) in Nigeria also developed and commercialized a semi-mechanized cassava lifter/harvester (Oni and Eneh, 2004). Amposah *et al.,* 2014 observed that the pressure applied on the lever was not sustainable for a constant optimum field performance of the harvester as a massive 540 watts is consumed in one hour of operation, which led to constant rests. Ogunjimi *et al.,* (2016) developed an instrumented rig for cassava harvesting for experimental purposes which was not suited for field harvesting of cassava. Amposah *et al., (2017)* evaluated the performance of an improved manual harvesting tool with some high levels of drudgery recorded and tuber damage. Rest periods in the utilization of the manual solutions of cassava harvesting ranged from 31 minutes of rest per hour to 36 minutes respectively.

However, none of these studies considered the use of hydraulic system as a means of aiding the lifting of the cassava from the soil. Additionally, the utilization of these solutions meant there was serious disturbance to the soil around the cassava stand after harvest which meant that considerable soil loss was a reality as well as considerable tuber breakage as a result of improper operation of the devices (Amposah 2011; Amposah *et al.*, 2014). Consequently the major aim of this study is to design and fabricate a low cost light, manually operated hydraulic cassava harvester which would produce minimal disturbance to the soil when harvesting. The study seeks to eliminate the high effort requirement in cassava harvesting through the use of hydraulic ram and plunger which will replace the human arm in the lifting operation. It is expected that the development of this harvester would improve cassava harvesting operations at the small scale level because of its simplicity in design and ease of operation.

MATERIALS AND METHODS

A manually operated hydraulic powered cassava harvester is conceived to replace significant human drudgery in the harvesting of cassava tubers. The components of the harvesting device include: The main frame, the support stand, the lifting arm/rail, lifting aid, lifting medium and clamp.

Minimum force to uproot a mature cassava tuber

The average force required to uproot one cassava plant is 1000 N and the average human force is 600 N (Campbell, 1990; Akinwunmi and Andoh, 2012). This means that the human effort must be complemented by the aid of a leverage tool to succeed in harvesting cassava tubers, hence the choice of a hydraulic ram and plunger.

The hydraulic system uses the Pascal's principle while the lifting device is based on the moment of forces. The free body diagram of the lifting procedure of a cassava harvesting procedure is shown in figure 1:

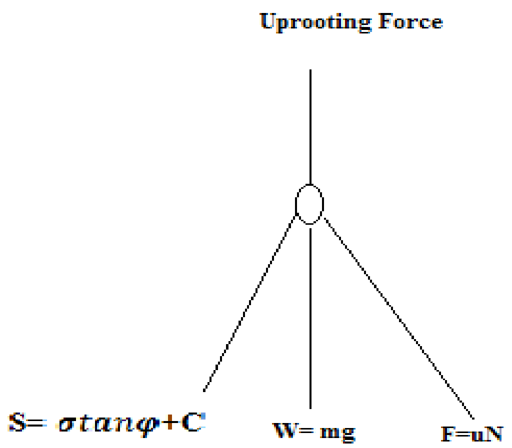

Figure 1: Free Body Diagram of the Cassava Harvesting Procedure.

For lifting of cassava tubers to be achieved, the uproot force must be greater than the weight of the tubers (W), shear strength of the soil (S) and the frictional resistance of the on the cassava tubers (F) shown in Figure 1. These are further influenced by the prevailing soil moisture and other conditions. Design Calculations

The force diagram of the lifting arm of harvesting device is shown in Figure 2.

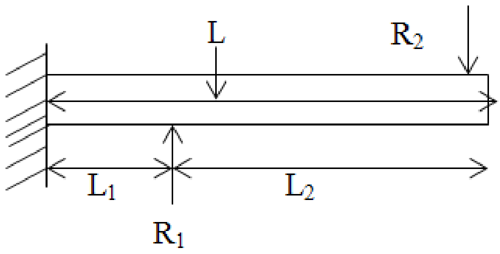

Figure 2: Force Diagram

Where: R_1 is the force produced from the lifting medium, R_2 is the reaction at the lifting end, L is the span of the lifting arm while L_1 and L_2 are distances from the main fixed point to the force and the reaction at the lifting end respectively.

The moment at R_2 = $R_2 \times L$ ....(1)

while the moment produced by the lifting force is

$R_1 \times L_1$ ....(2)

Since the force required to lift a cassava tuber is 1000 N, the moment required to lift the cassava tuber will be 1000L(Nm) .Thus, a moment greater than 1000(Nm) is required in the Anti clock wise direction to cause the lifting. The shear force and bending moment diagram is shown respectively in Figure 3

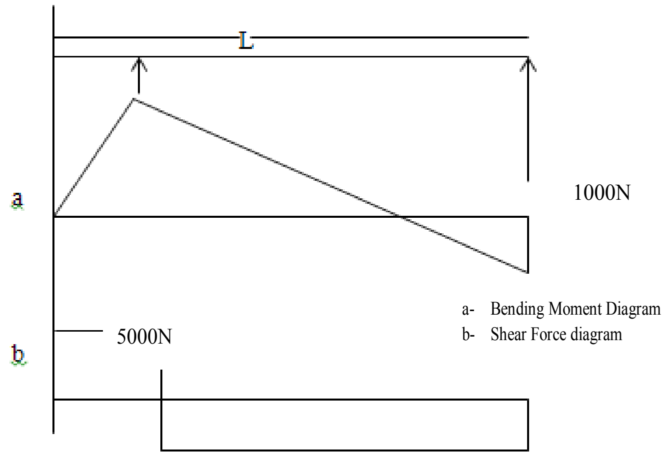

Figure 3: Bending Moment and Shear force diagram.

To withstand the shear force and bending moment as shown in Figure 3, the square shaped hollow steel of 900 mm long and dimensions 48 mm x 48 mm x 2 mm was selected

The hydraulic pressure in jacks is given by the formula (Kett, 1982)

$$hydraulic\ pressure = \frac{Effort\ at\ lever \times leverage(N)}{Area\ of\ plunger(m^2)} \quad ......(3)$$

The effort required in operating the hydraulic jack is given by Pascal's law

$$F_1 A_1 = F_2 A_2 \quad ....(4)$$

Where F_1A_1 and F_2 A_2 are the Force and areas at the plungers and ram respectively

Working stress

The stress imposed on the lifting procedure was obtained by the formula (Equation 5) given by Khurmi and Gupta, (2005):

$$\sigma = \frac{M}{Z} \quad ....(5)$$

Where: M is the bending moment and Z is the section modulus of the material. From calculations the hollow square steel section was preferred.

Design of Bolts

In order to achieve ease of fabrication and assembly, the members of the harvester were bolted at the base frame extension, the base fame support and the lifting arm connection to the main frame. The bolt selection was given by (Anonymous, 2006)

$$P_1 = 284d \quad ....6$$

Where: P_1 is the tension in the bolt and d is the nominal diameter of the bolt selected in mm. M16 bolts were selected for the lifting arm joint while M20 bolts were selected for the base frame extension which gives factors of safety of 8 and 10 respectively.

The base frame

This is responsible for the stability and support of the entire structure. It provides the strength needed for the entire harvesting operation. In the design for strength, the moment of inertias of the regular cross sections were examined and the cross section material selected was a hollow mild steel of square cross section. The shape of the base frame was chosen to be a trapezoidal cross section. The section is shown in Figure 4.

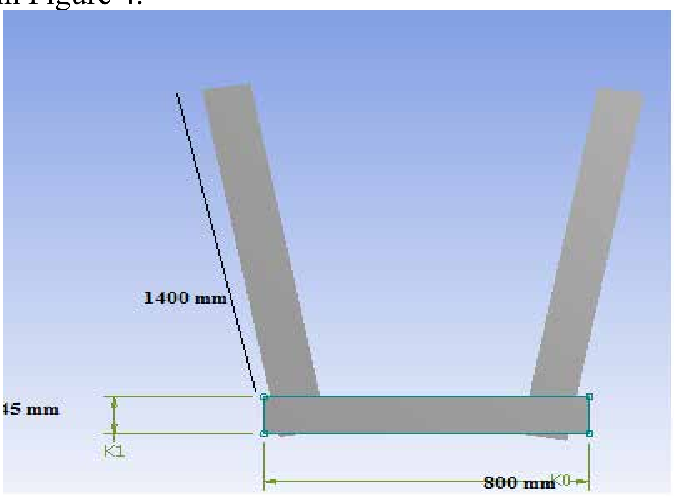

Figure 4: The base frame

Lifting assistance

To achieve this, a 5 ton capacity single acting cylinder (hydraulic jack) was employed for the lifting action. Other characteristics include: Working load limit – 5 tons, closed height – 200 mm, lift, 120 mm, extension screw height, 70 mm, maximum height, 390 mm, Piston diameter -70 mm Rod diameter -35 mm.

Support Stand

The support stand was welded at an obtuse angle of 120 and braced with bolted brackets of 10 mm thickness for rigidity and strength.

The conceptual design of the cassava harvesting device is shown in Figure 6 while the isometric drawing is shown in Figure 5.

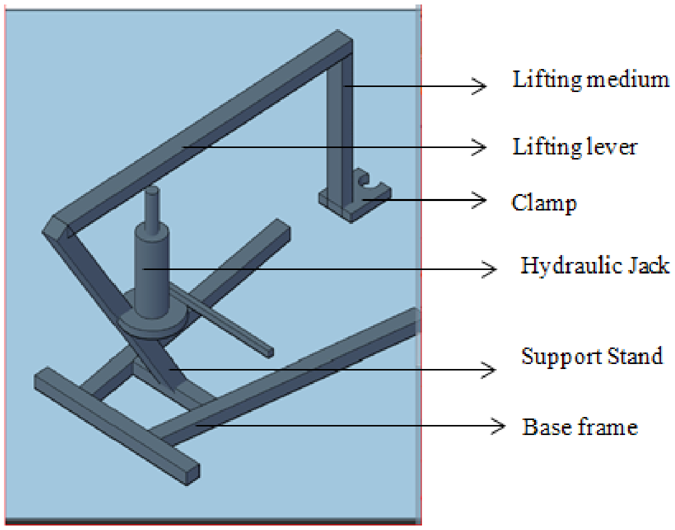

Figure 5: Conceptual Design

The cutting of the stem is expected to be done manually. The process of loosening the soil makes it possible for some essential nutrients to be shaken out of the root zone and expose the tubers to environmental and biological agents in the event that the harvesting is not completed due to fatigue on the part of the farmer. The adaptation of a hydraulic jack operated lifter will eliminate the need for soil loosening and the time spent in each of the unit processes before harvesting. The isometric view of the harvester is shown in figure 6.

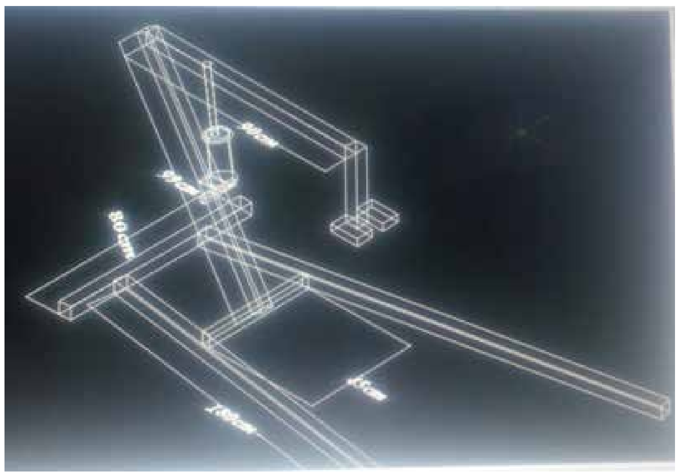

Figure 6: Isometric view of the design

Preliminary Test Procedure Study Area.

The performance of the hydraulic lifter (harvester) was carried out at the teaching and research farm of the Olabisi Onabanjo University, College of Engineering and Environmental Studies Ibogun campus Ogun State, Nigeria at coordinates 6°48'27" N and 3°5'55"E and the following physical parameters were be considered: time required in lifting a stand, number of tubers, weight of each stand and the force required. Agronomic parameters include: stem girth (cm), root yield (kg), maximum root diameter (cm), maximum root length (cm), maximum root depth, number of root tubers and soil penetrometer readings. The field capacity T (man-hour ha^{-1}) of the device is given by

$$T = \frac{1000 \times t}{n \times 3600} \quad ....(7)$$

where t = total time spent in harvesting(s),
n = number of plants harvested.

Soil Penetrometer Test

The Proctor Penetrometer Model H-4139 was used in measuring the method of test for establishing the penetration resistance of the soils as given by ASTM D1558

Moisture content determination

The formula for the indirect method of the determination of the moisture content is given by

$$: \frac{W_3 - W_1}{W_2 - W_1} \times 100 \quad ....(8)$$

Where W_1 *=weight of container with cover*
W_2 *=weight of container with soil*
W_3 *=weight of container with oven-dry soil,*

Instruments of Measurements

The measuring tape was used to measure the root length, and root depth,while the venier calliper was used to root diameter and stem girth, while the stop watch and weighing scales were used to measure the time to lift a stand and the weights of tubers harvested respectively. Microsoft excel was used for the data analysis.

The experiment was carried out by selected 20 random stands from a TME 419 mature cassava field which was 12 months.

RESULTS AND DISCUSSION

The fabricated units are shown in Figure 7 while field adjustment and set up is shown in Figure 8. Preliminary field testing of the device is shown in Figures 9, 10 and 11 respectively. The results of the agronomic and field parameters are shown in Table Data Analysis.

The correlation analysis carried out is shown in Table 2. The ANOVA is shown in Table 3. The model of fit is obtainable from Table 4.

Figure7 Fabricated unit

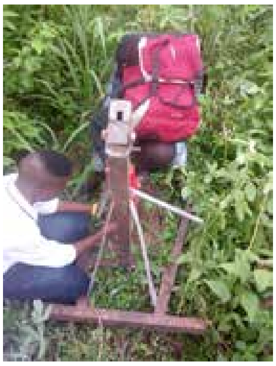

Figure 8 Field set up

Figure 9: Field Evaluation

Figure 10: Weighing of Harvested tubers

Figure 11: Measuremernt of tuber parameters

Table 1: Field Results showing some field harvesting parameters

Stem Girth(cm)	No of Tubers	Max root diameter cm	root depth cm	max root length cm	Root yield kg	Force Uproot N	Time s	Penetrometer Readings kg/cm²	Force uproot (kg)
3.752	7	3.939	30	17	0.5	544.455	30	17.18	55.5
6.3	7	4.58	40	40	3	568.98	35	16.56	58
4.701	6	5.29	55	53	5	588.6	30	18.13	60
2.271	6	5.15	42	26	2	559.17	28	17.17	57
5.02	5	4.74	43	34	1	549.36	25	17.08	56
2.71	9	3.38	34	30	0.5	544.455	30	17.39	55.5
3.4	5	3.5	34	30	0.5	544.455	23	17.08	55.5
4.29	3	6.45	22	18	1	549.36	13	17.39	56
6.1	9	5.7	36	30	2	559.17	23	17.08	57
5.2	9	5.2	45	38	1	549.36	26	17.70	56

Table 1: Field Results showing some field harvesting parameters ***-continued***

Stem Girth(cm)	No of Tubers	Max root diameter cm	root depth cm	max root length cm	Root yield kg	Force Uproot N	Time s	Penetrometer Readings kg/cm^2	Force uproot (kg)
3.9	8	6.39	42	30	1.5	554.265	32	17.08	56.5
3.8	10	4.68	35	30	1	549.36	21	17.08	56
3.95	7	5.48	42	34	0.5	544.455	29	17.08	55.5
6	6	5.8	44	38	3	568.98	28	17.08	58
4.21	6	7	30	23	3.5	573.885	28	17.08	58.5
4.11	12	5.21	37	27	2	559.17	33	17.08	57
4.21	6	6.6	37	23	2	559.17	16	17.08	57
4.55	9	6.02	32	24	3	568.98	30	17.08	58
4.1	6	6	31	20	2.5	564.075	25	17.08	57.5
2.7	7	7	30	20	4	578.79	35	17.08	59

Table 2: Correlation of some Field parameters

	Stem Girth(cm)	No of Tubers	Max root diameter	root depth	max root length	Root yield	Force Uproot Newtons	Time
Stem Girth(cm)	1							
No of Tubers	0.016101	1						
Max root diameter	0.104927	-0.17541	1					
root depth	0.298869	0.118504	-0.16925	1				
max root length	0.467694	0.082668	-0.27764	0.881933	1			
weight of tubers	0.219269	-0.06774	0.529884	0.245538	0.273306	1		
Force Uproot Newtons	0.219269	-0.06774	0.529884	0.245538	0.273306	1	1	
Time	-0.05827	0.418608	-0.11978	0.310181	0.260326	0.368918	0.368918	1

Effect of Field parameters: The maximum root lenght strongly correlated with stem girth while maximum root lenght and weight of tubers were influenced by root depth and maximum root diameters respectively. The force required in the uprooting procedure is most influnced by the root diameter whille the time spent is most influenced by number of tubers.

Table 3: ANOVA showing the interactions among field parameters

	df	SS	MS	F	Significance F
Regression	2	208.9509	104.4754	4.258689	0.031674
Residual	17	417.0491	24.5323		
Total	19	626			

The F value of the ANOVA for the opbservation shows that there is a significant level of interaction among parameters which is further confirmed by Table 2..

Table 5: Model of fit

	Coefficients	Standard Error	t Stat	P-value
Intercept	14.61653	4.563964	3.202596	0.005218
No of Tubers	1.242344	0.55314	2.245986	0.038286
weight of tubers	1.77251	0.881214	2.01144	0.060409

CONCLUSION

The minimum time used in uprooting a cassava stand is 13 seconds which favourably compares with Ogunjirin *et al.,* (2016) who obtained a value of 10 seconds with an electrical motor driven rig. Total time spent in harvesting is 540 seconds. The field capacity of the device calculated was 75 man hr ha^{-1} which is more than the capacity recorded by Amposah *et al.,*(2014).No cassava root breakage was observed during the harvesting procedure giving the lifting efficiency of the device to be almost 100%. the cost of fabrication of the project was N30,100 and further ways of reducing the production cost should be investigated to make the study more appealing to the rural farmers. Similarly, clamp mechanism could be developed and adapted that will be different from the current method of using nuts and bolts.

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