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Development of a tractor-mounted cocoyam *(Xanthosoma* spp.*)* harvester

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Abstract

A tractor – mounted harvester for cocoyam *(Xanthosoma* spp.*)* was designed and fabricated at the Federal University of Technology, Akure using locally available materials. The major components of this machine are; the blade, ridge roller, variable angle bevel gear, and a cleaning web fabricated from flat leather belt slatted with steel rods which is powered from the tractor Power – take – off shaft (P.T.O). Field tests were conducted to evaluate the effect of different levels of operational parameters on the performance of the implement. The operational parameters were forward speed (v), rake angle (α) and web speed (n). The harvester was operated at the forward speeds of 2, 4 and 6 km/h, rake angles of 15˚, 20˚ and 25˚ and web speeds of 540, 1000 rpm. The soil moisture content during field experimentation was 9.46 ± 1.02%, and bulk density was 1.18 ± 0.22 g/cm^3. These combinations were tested on a factorial basis employing a split - split plot design with three replications. The performance of the implement investigated was the mass of successfully harvested tubers and tuber damage. Cocoyam cormels were harvested from 10m long rows of crops on clay loam with a spacing of 0.8m x 0.6m according to each treatment. The mean cluster width and depth were determined to be 39.53 and 20.02 cm, while the means of the cormels weight per cluster and number of cormels per cluster are 1.72 kg and 6.6, respectively. From the results, a mean harvest rate of 12.02 t/h and mean digging efficiency of 84.2% were obtained. This implies that, while the harvester can be operated for higher field capacity at 6 km/h. 20˚ blade angle with the cleaning web, powered at 1000 rpm, the optimum condition of digging up most cocoyam cormels with minimum dug losses under the condition of these tests is at 4 km/h, 20˚ blade angle and 540 rpm web speed. The field tests also revealed that machine performance was limited by delays due to clogging and machine adjustments and a high percentage of tuber damage (55%). The analysis of variance performed on the descriptive statistics for machine performance variables obtained showed that machine performance variables were not significant at $P < 0.05$ for any of the parameters tested.

Keywords: Blade, Ridge Roller, Cleaning Web, Cocoyam.

Abbreviations: TRT – Treatment, DEFF-Digging efficiency (%), HC - Harvested cormels (kg), DL - Dug loss (kg), ϕ - Angle of shearing resistance, C – Cohesion, Cα – Adhesion, σ - Normal stress, w - Cluster width and , A - Cross sectional area. P = Drawbar pull , F_v = Vertical force, F_h = Horizontal force, D = Weight of loaded conveyor , B = Weight of empty wagon (Frame) , γ - Soil unit weight.

Introduction

Huge advances have been made in the mechanised harvesting of most temperate crops. This is not so for tropical crops, especially tuber crops. Most of the harvesters developed have brought about a remarkable reduction in the drudgery, labour requirement and production cost of such crops. Cocoyam (*Xanthosoma spp.*) is one of the popular tropical tuber crops; others are yams, cassava, ginger and sweet potato. Cocoyam constitutes a major part of food consumed in Nigeria, and also in the tropical regions of the world. The edible corms are roasted, cooked or pounded into paste for food (Phillips, 1977). The tender leaves and petioles are also eaten either as vegetables or meat supplements. Among its advantages over related tuber crops like yam and cassava is the simpler external morphology and husbandry practices; non possession of a woody stem, not requiring stakes for mechanical support and vegetative propagation from crop parts that are not of considerable economic importance. Early attempt to mechanise the harvesting of tropical root crops began with the use of the plough. The plough is a tractor or oxen drawn digger, which has a share and raising fingers as the primary components. In some cases, sifting fingers are attached at the back of the raising fingers for better separation. The potato spinner consists of a flat horizontal share that passes under the crop to loosen and lift the soil and crops. This mass is then passed into a series of rapidly rotating tines fixed on a hub which is either PTO or land wheel driven. The tines shatter the soil and separate

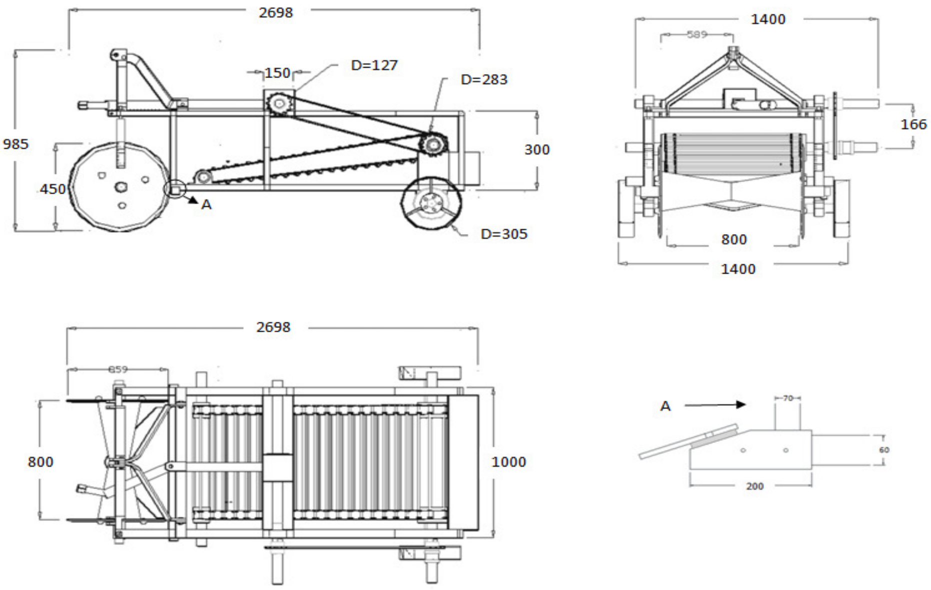

Fig 1. Orthographic drawings showing major dimensions of the machine components

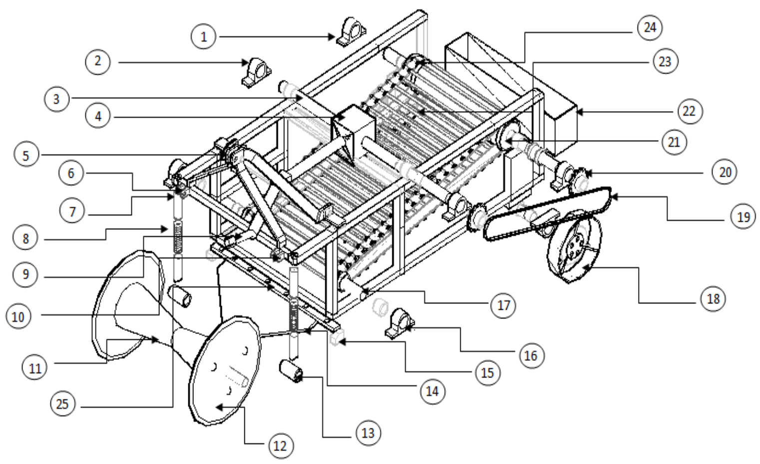

Fig 2. Exploded assembly drawing of component parts of the cocoyam harvester

the crop. The elevator digger consists of a share, which raises the soil into a single continuous apron of steel rods (link conveyors) or two separate chains. The soils fall off as the crop moves to the back of the elevator that is given a shaken action by agitators and the potatoes are returned to the ground for hand picking. The manned elevator digger was developed initially as semi automatic harvester. Pickers are stationed on the extended or an additional conveyer of the machine to pick out either potatoes or rubbish to produce a clean sample (Hawkins, 1980). The complete harvester performs digging, separation, cleaning and delivery of tubers in a one pass operation of the harvester. In the present work, a harvester was developed to assist in the mechanised harvesting of cocoyam which is widely grown in Nigeria. A study of the reliability of the machine has been reported in Akinbamowo *et al,* (2009)

Materials and methods

Design Considerations

In the design of the cocoyam harvester, consideration was given to the following factors;

i. The machine should achieve a reduction in the overall production cost
ii. It should increase the productivity of farmers currently harvesting manually.

iii. It should lead to the reduction of drudgery and tedium associated with the manual process of harvesting.
iv. It is to achieve decrease in root losses and damage.
v. The machine should be able to achieve a forward speed of 3 km/ hr as recommended for similar root crop harvesters in Misener *et al*. (1984).
vi. An inter and intra row spacing of 60cm x 80cm for cocoyam is recommended by Onwueme (1982). Therefore a minimum web width of 80cm is considered good for design.
vii. The cost of the machine should be affordable by farmers and cheaper than similar imported machines.
viii. Materials used for the fabrication should be readily available and be such that will reduce the total power requirement.
ix. The machine should be adaptable to the common varieties of cocoyam and changing operational parameters.

Description of the machine

This implement is designed to work as the second stage of a three stage harvesting operation for cocoyam. The first stage is to combine a topping operation with windrowing. This stage is to remove the vegetal mass of the crop including the weeds growing on the field to prevent the clogging on the elevator digger. The implement (Fig 1) is semi - mounted and attached into the tractor 3 – point linkage while the cleaning system is powered from the tractor PTO shaft. The Ridge roller (11) is the frustum of two cones inverted and joined at the smaller radius. It is made from steel tube and filled with concrete as ballast. The function of the ridge roller is to break soil clods and exert pressure on the soil to facilitate corm/cormels/soil separation. Two Disc coulters (12) are fixed at both ends of the roller to enhance a smooth cut and lifting of soil from the ridges. The digging blade (14) is almost triangular in shape and sharpened at the edge to enhance penetration is made from a rectangular steel section. At the rear part, the blade is fixed firmly to a flat bar (15) on the rectangular frame by means of rivets for easy maintainability and replacement. The blade is oriented at an angle of 15 - 25° to the horizontal so that upward soil forces will throw the cormels into the elevated digging web. The blade is designed to dig into the soil up to a maximum depth of 30 cm. Two Compression springs (7, 8) are fixed on the ridge roller so as to be able to achieve a constant depth of cut in spite of the unevenness of the field. Soil - cormel separation and cleaning is done on the Continental Web, which is made in form of a slatted conveyor with rod links (23) on flat belt (24). It is designed to accommodate a ridge of cocoyam on a 1m width on a total conveyor length of 1.2 m (center to center) so as to be able to accommodate two stands of cocoyam spaced at 60 cm apart on the ridge. The web is inclined at an angle of 10 to the horizontal to achieve a vertical rise of 0.26 m to enhance cleaning. The operating speed of the web is 2.5 m/s so that it has a capacity of 59.72 kg of soil and crop materials per second. 540 or 1000 rpm p. t. o. speed is provided to a variable

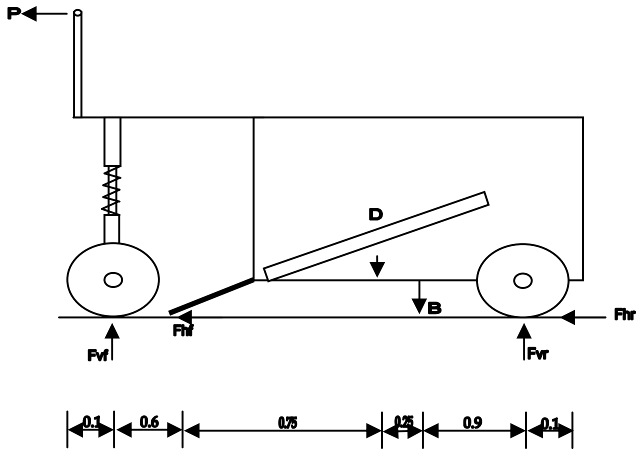

Fig 3. Vertical cross section showing forces acting on major machine components

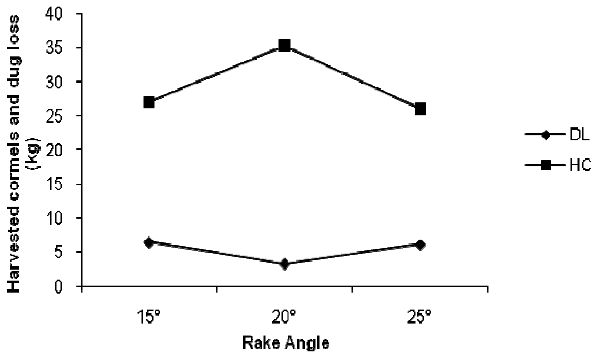

Fig 4. Effect of rake angle on yield and dug loss

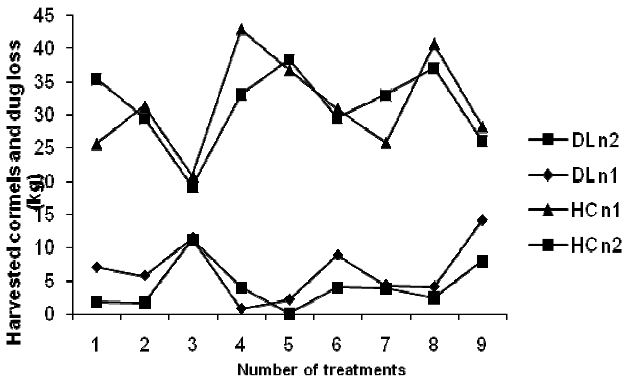

Fig 5. Effects of 1000 (n_2) and 540 (n_1) rpm web speed on yield and dug loss with nine pairs of treatments

angle bevel gear (4) at the top of the implement through a Universal joint (9) from the Tractor. 25 kW of power is transmitted from the variable angle bevel gears to run the continental web rollers from a Chain (19) drive positioned at the side of the digger. Two Land wheels (20) are provided on a rear axle shaft for mobility on the field and for transport. All component parts are assembled and carried on a Frame which is mainly made from a rectangular steel section 150 x 75 x 6.3 mm to provide adequate structural support for the proper functioning of the machine.

Design Analysis of the Harvester

The major components of the machine requiring design include the blade, power transmission system, cleaning web, ridge roller, rear axle, frame, hopper and the linkage system.

The blade

A flat, 80 cm wide, V – Shaped blade was chosen for the machine to achieve low draught requirements and higher digging efficiency. The soil / soil and soil/metal parameters used are; ϕ = 25°, C = 20 kN/m^2, Cα= 2.6 kN / m^2 (Crossley and Kilgour, 1983). Surcharge on the blade was calculated from:

$$q = \frac{w}{A} \qquad (1)$$

Where: Cα = adhesion, C = cohesion and ϕ = Angle of shearing resistance, w = cluster width and A = cross sectional area. It was found to be 0.23 kN / m^3. The aspect ratio for wedge transition point (K) was found to be 0.8. According to Payne (1956) if K > 1.0, tine is narrow, therefore wide tine analysis was used for the design. The passive force P per unit width of blade is determined from the General soil mechanics equation (Godwin and Spoor, 1977)

$$P = \gamma Z^2 N\gamma + CZN_{ca} + qZN_q \qquad (2)$$

was found to be 5.31 kN / m. Draught force per unit width is given by

$$D = P\mathrm{Sin}(\alpha + \delta) + C_a\mathrm{Cos}\,\alpha \qquad (3)$$

Also the vertical soil force per unit width of soil is given by

$$V = P\mathrm{Cos}(\alpha + \delta) + C_a\mathrm{Sin}\,\alpha \qquad (4)$$

The draught force and vertical soil force were found to be 3.77 kN / m^2 and 4.28 kN / m^2 respectively.
Then from:

$$\frac{I}{c} = \frac{b\,h^2}{6} \qquad (5)$$

the final blade thickness (h) of 6.88 mm or approximately 7 mm was selected.

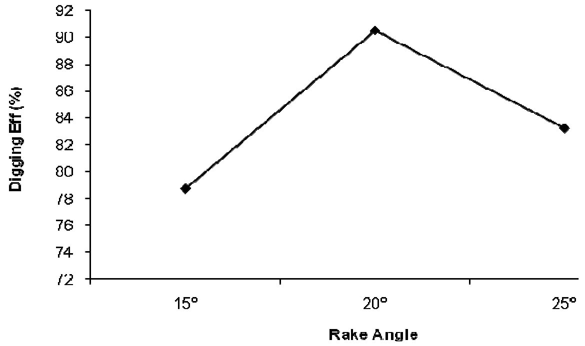

Fig 6. Effect of rake angle on digging efficiency

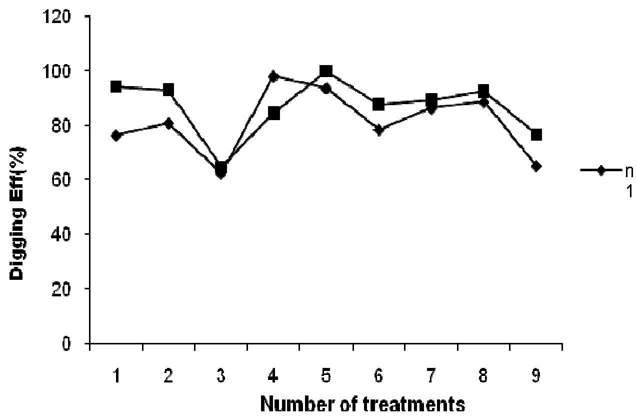

Fig 7. Effects of 1000 (n_2) and 540 (n_1) web speed on digging efficiency

2.3.2 The power transmission system

1000 or 540 rpm speed is provided to a variable angle bevel gear at the top of the implement through a universal joint from the Tractor. Power is transmitted from the variable angle bevel gears to run the continental web rollers from a chain drive positioned at the side of the digger. The transmission system consists of the following components:
1) Variable angle bevel gear that is connected to the tractor PTO shaft through the Standard universal coupling shaft and both the input and shaft rotates at 540 rpm.
2) Chain and sprocket. The bevel gear transmits rotary power through the chain and
sprocket sited at the side of the machine to the cleaning web. The design of the chain and sprockets was done according to the methods outlined in PSG TECH (1982).

The cleaning web

The design uses the continental web where 68 round steel rods of 0.125 cm diameter and total mass of 42 kg are

Table 1. Descriptive statistics of treatments and machine performance variables

TRT	DEFF	HC	DL
1	76.45±11.90	25.60± 6.47	7.03 ± 3.61
2	81.02±18.98	31.30± 9.20	5.73 ± 5.73
3	62.50 ± 17.26	20.77± 7.38	11.47± 5.76
4	94.39 ± 5.61	35.37± 5.19	1.70± 1.70
5	93.28 ±5.29	29.47± 5.22	1.67±1.20
6	64.97 ±11.55	19.13± 1.69	11.17± 4.07
7	98.13 ± 1.87	42.80+ 3.23	0.73± 0.73
8	93.76 ± 6.24	36.67± 4.59	2.17±2.17
9	78.52± 11.04	30.90± 3.67	8.80±4.70
10	84.66 + 4.79	33.03± 4.59	3.97±2.37
11	100± 00	38.30±4.45	0.00± 0.00
12	87.89± 7.26	29.5± 5.45	4.0±2.08
13	86.36 ± 7.20	25.77± 1.79	4.27± 2.18
14	88.77± 11.23	40.63± 8.32	4.07± 4.07
15	65.25± 17.78	28.20± 8.52	14.10± 7.31
16	89.49± 4.07	32.97± 1.96	3.87± 1.45
17	92.69 ± 7.31	37.00± 5.50	2.43± 2.43
18	76.94 ± 8.89	26.03± 2.82	7.90± 3.18
Avg.	84.17± 2.50	31.30± 1.37	5.28± 0.88

spaced 5.5 cm and fixed by rivets on a fabric band of webbing at the two ends. The web was designed as a slatted conveyor according to the methods outlined in PSG TECH (1982) and Alexandrov (1981). The operating speed of the web is 2.50 m/s so that it has a capacity of 215.46 tonnes of soil and crop materials per hour. The conveyor rollers (Head and take up rollers) are held in two shafts that were designed according to Hall *et al.* (1988) to be 48 mm and 35 mm.

The Ridge Roller

The function of the ridge roller is to crush soil crumbs and assist the separation of the soil / cormels prior to lifting. The steel casing of mass 3948.55 x 10^{-3} kg and volume of 503 x 10^3 mm^3 was ballasted up to 50% of its volume with dry sand of mass 23.55 kg. Two steel vertical cutting discs of 0.45 diameter and 3.7 kg are attached to the ridge rollers to cut along the edges of rows of ridges to minimize the lifting of roots and the remnants of vegetation

Rear axle shaft

The rear axle shaft was designed taking into consideration the totality of the horizontal loads and vertical loads on the rear axle. The diameter of the shaft was found to be 90 mm. Figure 3 illustrates the free body diagram of digger showing the external forces acting on the implement.

Compression springs

The ridge roller is to be held by two compression springs made from carbon steel that was designed according to the procedures of the Spring Research Association (1974).

The Frame

The frame is the component that holds all other parts together for efficient functioning. For the design, it was considered to be two rectangular steel beams using Structural Hollow Section for structural stability and rigidity. The steps are outlined in AISC (1973), Roundal *et al,* (1992) and Baumister *et al,* (1978).

The three point linkage

Standard dimension of 3-point linkage for this category of implements are selected from dimensions available in ASAE standard S 217.10 (1989).

The hopper

The wooden hopper is conveniently placed under the tail end of the conveyer for collection of cormels. The total mass of wooden hopper is 22.85 kg

Testing of Harvester

Workshop tests

Following the fabrication and assembly of the various components of the prototype harvester, the harvester was coupled to the 3 point linkage and PTO shaft of a STEYR - URSUS 5313 tractor. The PTO drive was engaged at 540 rpm while the tractor is in a stationary position so that the transmission system and continental web could be observed under no load condition. This test was repeated for ten times using the 540 rpm and 1000 rpm PTO speeds before the machine was driven to the field for further tests. During each of these static tests the behaviour of the various systems; the universal coupling, the bevel gear, chain and sprocket drive and the elevator web were observed with regard to the vibration, alignment and rigidity of the various component parts and necessary adjustments were made as required

Field experimentation

The performance of the prototype harvester was evaluated under different operational conditions. The tests were to determine the machine output for the major indices of functional and quality performance efficiency. Three operational parameters varied during the field tests were: a)

Table 2. Summary of optimum condition for use of Harvester

Performance Indicator	Desired Values	Result Obtained		
		Forward Speed	Rake Angle	Web Speed
Rate of Work	Max. Values	6 km/h	20˚	1000rpm
Crops Harvested	Max. HC	4 km/h	20˚	540 rpm
	Min. DL	4 km/h	20˚	540 rpm
Digging Efficiency	Max. Values	4 km/h	20˚	540 rpm

Forward speed (v) b) Rake angle (α) and PTO speed (n). The forward speed of 2.0, 4.0 and 6.0 km/h used during the tests were monitored on the tractor speedometer on the instrument panel. The three levels of rake angle 15˚, 20˚, 25˚ was varied through a device attached to the frame while the two levels of web speed (n) 1000rpm, 540 rpm (n) was varied directly from the tractor PTO gear system. Other soil and crop conditions are assumed constant. The experimental layout of three replicates of a split plot design in a 3 x 2 x 3 factorial design. This gives a total of 54 sets of data for all the parameters tested. The experimental plot consists of a single replicate of the eighteen treatments.

Results and Discussion

The descriptive statistics for the results obtained are tabulated in Table 1

Harvested Cormels

Total mass of harvested cormels for the experimental plot was 1.69 tonnes. The mean values of the mass of harvested cormels per treatment are shown in Table 1. When extrapolated to estimated yield on hectare basis, the yield was found to be 39.13 tonnes per hectare. This result is higher than the average figure for tannia in Nigeria which is 12.20 tonnes / ha according to Onwueme (1982) and within the 25 – 40 tonnes/ha reported in Ekere – Okoro *et al.* (2005). Onwueme (1982) also cited crop yield of up to 37 tonnes per hectare for Pueto Rico, though crop yield generally depend on the condition and method of production. This slight increase in yield over the national average might be indicative of the improved tendering and husbandry practices given to the crops. As an experimental plot, improved handling may have led to higher yield. In addition, no sign of pest infestation that may account for yield reduction was noticed throughout the duration of the study.

Dug losses

The total mass of dug cormels collected from the soil is 285 kg (6.60 tonnes / ha). Maximum value is 14.10 kg at treatments T15. This is considerably higher than the results recorded for sugar beet in Davis (1977). This may be due to the influence of speed of operation and implement rake angle on the treatments.

Effect of rake angle on yield and dug loss

The effect of rake angle on the variables DL and HC shows that DL lowest at 20° (3.3 kg) and HC (35.2 kg) is highest at the same operational parameter. This is slightly lower than 26° - 90° recommended nose angle for yam harvesters in Itodo and Daudu, (2003). Dug loss at 25° (6.1 kg) is lower than 6.5 kg for 15° rake angle because of the greater angle of disc penetration to scoop cormels from the soil. Values of harvested cormels for the 25° rake angle is slightly lower than for 15°, although the reverse case is the commonest. Conventionally, the less acute the rake angle resulting in lower tool penetration, the lower the draft requirement that results in fewer amounts of soil and tubers lifted out of the soil (Davis and Hearns,1977). The probable reason for this trend may be misalignment of tractor outside wheels such that the tractor wheels sometimes run on ridges bordering the one harvested during the field tests.

Effects of web speed on yield and dug loss

The eighteen treatments considered for web speed consist of nine treatments each of n_1 and n_2. The illustration of effects of web speed on DL and HC in Fig.5 shows that values of n_1 (1000 rpm P.T.O. speed) are higher than for n_2 (540 rpm) in respect of HC in six of the nine pairs of treatments compared. Similarly values of n_2 are lower than n_1 in eight of the nine pairs of treatments measured. Variations in both operational parameters under study for both variables are not very wide and result obtained was not significant at $\alpha = 0.05$. Maximum values for HC for n_1 is 42.8 kg and n_2 is 38.3 kg. For DL maximum values are 14.1 kg (n_1) and 10.2 (n_2). Minimum values in respect of HC are 20.8 kg (n_1) and 19.1 kg (n_2). For DL, minimum values are 0.7 kg (n_1) and 0.0 (n_2).

Digging efficiency

The digging efficiency (DEFF) ranges from a maximum of 100% in T11 to 62.50 % in T3 as shown in the descriptive statistics presented in Fig. 4.10. Overall, mean digging efficiency for the test is 84.17 %. This slightly higher than 68.3 % obtained in Ogunlowo (1990) on cassava and 75% - 83% obtained in Bricero and Larson (1972) in Makanjuola *et al*. (1973).

Effect of rake angle on digging efficiency

The maximum value of digging efficiency of 90.5% was obtained at 20° rake angle followed by 83.2% at 25° and 78.2% at 15° (Fig. 4.12). Thus on account of digging efficiency alone and based on the conditions of these tests, the 20° rake angle appear to be the most suitable for complete digging out of cormels, followed by the 25° rake angle

Effects of web speed on digging efficiency

The effects of changes in web speed on the digging efficiency of the experimental plot appear to follow the trend of the result of harvesting rate. The values of treatments n_1 and n_2 compared rarely differ greatly among the treatments although the 540 rpm P.T.O speed (n_2) appear to be marginally superior to 1000 rpm PTO speed (n_1) in eight of the nine pairs of observations. The maximum values are 100% in respect of n_2 and 98.1 % in n_1. Similarly, minimum values are 62.5 % (n_1) and 65 % (n_2). Maw *et al.* (1998) found that a similar prototype harvester for sweet onions functioned most smoothly with a lifting belt speed of 100 – 125% of ground speed.

Optimum condition for use of Harvester

Based on the result of the test, a summary of the recommended operational conditions for the use of the cocoyam harvester to obtain desired values of performance are presented in Table 2. The results show that, while the harvester can be operated for higher field capacity at 6 km/h, 20˚ rake angle with the cleaning web powered at 1000 rpm, the optimum condition of digging up most cocoyam cormels with minimum dug losses is at 4 km/h, 20˚ rake angle and 540 rpm web speed.

Conclusion

A semi mounted, power – take – off (P.T.O.) driven cocoyam harvester was designed and fabricated from locally available materials. The performance of the harvester was evaluated in the laboratory and with field tests. The tests have shown that the prototype cocoyam harvester satisfied most of the general and functional requirements of a machine in this category. It is simple in design and mobile as a semi mounted implement. Power and labour use is low and parts are locally available. The mean harvesting rate at all values of forward speed of 12.02 tonnes/h give superiority over previous works on similar prototypes by Jakeway and Smith (1979); Ogunlowo 1990). Maximum total power requirement of 27 kW at 4 km/h is higher than 13.30 kW in Kang *et al.* (2001). However dug losses of 6.60 tonnes/ha are higher than recorded on similar commercial harvesters. In addition, high tuber damage, frequent breakdown and delays recorded during the field tests, among others, represented practical limitation during the field test and they prevented the full expression of treatments. However, according to Maw *et al*. (2002) such cases are common on machines during the first field test and often result in an increased understanding of the harvester prototype.

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