Design and Fabrication of a Semi-Automatic Cassava Planter

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Abstract. A single-row semi-automatic cassava planter was developed at the Department of Agricultural and Environmental Engineering, Federal University of Technology, Akure, Nigeria. The planter consists of a hopper, a roller-picker, cutting unit, a belt conveyor acting as the metering device, a double disc furrow opener, a double disc furrow coverer, a gear transmission system, the frame and the land wheels. The planter is driven by a tractor of 41 horsepower (30.6 kW). The field test showed that the semi-automatic cassava planter satisfied the functional requirements of a planter. The planter was found suitable at a functional efficiency of 95.45%. The evaluation of the performance of the planter to determine its relationship with the forward speeds, land preparation, and lug arrangement of rigid wheel will further be carried out. This development will reduce the cost of planting by eliminating the extra labour required behind the tractor by the presently available commercial planters. It will also increase cassava production, reduce the present drudgery in planting cassava as well as attracting the youths into agricultural production.

1. Introduction

Nigeria has been recorded as the largest producer of cassava in the world with 46 million tonnes [1]. Currently, cassava roots can be processed into a variety of food products such as gari, lafun, and fufu, but the significance of cassava as a source of energy intake in human diet particularly in the tropical regions of the globe as well as a source of carbohydrates for production chips and pellets as animal feeds and alcoholic materials have been recorded [2, 3, 4, 5, 6]). Odigboh [4] reported that cassava starch as an ingredient in the production of drugs, chemicals, carpets and coagulation of rubber latex.

Growing cassava generally needs from soil preparation to harvesting 75 – 125 persons per hectare [7]. In 2007, the world produced more than 228 million tonnes of cassava and Africa accounted for 52 % of the estimate. According to Food and Agriculture Organization of the United Nations estimates, Africa exports only one million tonnes of cassava annually [8]. Most of the planting is done manually using cutlass to lift the soil and insert the stem to about 10 cm into the soil and cut the remaining off from the buried stem. Recently, National Centre for Agricultural Mechanization (NCAM) attempted the development of a mechanical planter which was about 75 % complete as reported. It was conclusively claimed that mechanical cassava planter was not commercially available in Nigeria [9, 10]. The few ones sighted belong to research institutes and universities.

Freshly harvested stem ranging between 2-5 cm diameter majorly from the lower and middle part, not the green are recommended for planting [1, 11, 12]. A cassava stem cutting machine was designed,
fabricated, tested and found suitable by Ikejiofor and Okwesa [13]. A cassava stem cutting (stake) 20-25 cm in length and diameter of 2-5 cm could be planted per hole, either in a horizontal, vertical or slanting position to a depth of 5-10 cm depending on type and situation of the soil [14, 15]. In some nations, such as Brazil or Colombia, some mechanical planters for cassava have been developed. Most of them horizontally plant cassava. At the Federal University of Technology, Akure, Nigeria, a manually-fed cassava planter tested with field capacity of 0.28ha/h and field efficiency of 73.1% was designed and fabricated [16]. The major components of the planter are the frame, disc furrow opener, cutting device, operator seat, stem tube, press wheel, stem container and the land wheels; it was operated with Massey Ferguson tractor of 41 kW.

The labour shortage resulting from rural-urban migration in Nigeria and the current trend towards greater demand for cassava as raw materials for industrial manufacturing of starch and alcoholic products and the increase in exports to China and other advanced worlds have established the need to enhance the planting technology of cassava so that current labour shortage can be addressed by replacing it with a mechanical cassava stem planter that will reduce the cost of planting cassava by eliminating the extra labour required behind the tractor for placement of the cassava stems for mechanical planting as well as providing such labour for other cassava production and processing activities for the current and future demand for cassava and its products. The research is therefore about the design and fabrication of a semi-automatic cassava planter.

2. Materials and Methods
2.1 Design Considerations
The planter should be able to:

a. hold cassava stems with the provision of a hopper.
b. pick a cassava stem with the provision of a roller picker at the base of the hopper.
c. The planter should be able to cut the cassava stem into stakes of desired length.
d. transfer the stakes to the planting unit and place it in the furrow by providing a belt conveyor that serves as the metering device.
e. plant the stakes according to the space requirement.
f. open furrow to a desired depth on a prepared land.
g. cover the furrow optimally.
h. plant cassava stems of different varieties.
i. reduce labour requirement unlike the currently available cassava stem planters that require extra labour behind them.
j. A tractor of 41 horsepower (30.6 kW) should be able to power the planter

2.2 Design Analysis
2.2.1 Hopper Design. The hopper (Figure 1) is trapezoidal outside but inclined inside at 40° to ensure free flow of the stems. The materials for the hopper were 2mm thick. The volume of the hopper was determined as 0.0475 m³ using (equation 1), the capacity of the hopper in mass was determined as 19 kg using (equation 2) and the weight of the hopper was determined as 346.5 N using the appropriate equations as follows;
Volume of the Internal Hopper

\[
Volume\ of\ the\ Hopper = \frac{1}{2} (AB + 1H) \times BF \times JH
\]

= 0.0475 m\(^3\) \hspace{1cm} (1)

Capacity of the Hopper:

\[
Mass\ of\ the\ Stem = Density\ of\ Cassava\ stem \times Volume\ of\ the\ Hopper
\]

= 19 kg \hspace{1cm} (2)

where density of cassava stem is 400 kgDMm\(^{-3}\) \hspace{1cm} [17].

Weight of the Hopper:

To calculate the weight of the hopper, it is important to determine the surface area and the volume of the hopper materials.

Surface Area of the Hopper Materials, \(S_{Ah}\):

Surface of the External Side of the Hopper, \(S_{Ahe}\)

\[
S_{Ahe} = 2\left[\frac{1}{2} (AB + DC) \times Height + (BC \times CE)\right]
\]

= 1.552 m\(^2\) \hspace{1cm} (3)

Surface Area of the Internal Side of the Hopper, \(S_{ahi}\)

\[
S_{ahi} = (AI \times AG) + (BF \times BH)
\]

= 0.555 m\(^2\) \hspace{1cm} (4)

The surface Area of the Hopper Material, \(S_{Ah} = S_{Ahe} + S_{ahi}\) \hspace{1cm} (5)

The surface Area of the Hopper Materials = 2.107 m\(^2\)

Volume of the Hopper Material, \(V_{hm}\):

\[
V_{hm} = S_{Ah} \times t_{m}
\]

= 0.0042 m\(^3\) \hspace{1cm} (6)

where \(t_{m}\) is 0.002 m (thickness of the mild steel used)

Mass of the Hopper Materials, \(M_{hm}\):

The mass and weight of the hopper material can be determined by using equations 7 and 8.

\[
M_{hm} = V_{hm} \times \rho_{hm}
\]

\[M_{hm} = 32.97\ kg\]

where \(\rho_{hm}\) is the density of mild steel=7850 \hspace{1cm} [18]

To determine the weight of the hopper material, \(W_{hm}\), we have;

\[
W_{hm} = M_{hm} \times g
\]

= 323.4 N \hspace{1cm} (8)

where \(g\) is the acceleration due to gravity
The weight of the hopper is therefore 323.4 N

2.2.2 Design of the Machine Shafts. The diameter of the driving shafts of the cutting unit, the roller-picker and axles of the land wheels were determined using equation 9 [18]. The diameters of the two driving shafts and the roller-picker were each determined as 28 mm. Therefore, shafts of 30 mm diameter were selected for each of the shafts of the cutting unit and the roller picker. The diameter of the axles was each determined as 30 mm and 30 mm shaft was therefore selected.

\[
d^3 = \frac{16}{\pi S_s} \sqrt{(k_b M_b)^2 + (K_f M_f)^2}
\]  

(9)

where, d is the Shaft diameter; S_s is 55 x 10^{-6} N/m², the allowable stress for mild cast steel; M_b is the maximum bending; K_b is 1.5, the shock and fatigue factor for bending moment; K_f is 1, the shock and fatigue factor for torsional moment and M_f is the maximum torsional moment.

2.2.3 The Length, Speed, Power and the Capacity of the Belt Conveyor

Length of the Conveyor Belt, L:
The length of the belt was determined as 1646 mm using equation 10 [18]

\[
L = \frac{\pi}{2} (d_1 + d_2) x + \frac{(d_1 - d_2)^2}{4x}
\]  

(10)

where, d_1 and d_2 are the pulley diameters and x is the centre distance,

Speed of the Belt Conveyor, V:
The speed of the belt conveyor was determined as 1.015 m/s using equation 11 [18]

\[
V = \frac{\pi D N}{60}
\]  

(11)

where D is the diameter of the driving pulley and N is the number of revolutions per minute.

Power Required by the Conveyor:
The required power of the conveyor was calculated as 2.53 Watts using (equations 12), (13), (14) and (15) (PSG TECH, 1982),

\[
Power (Watt) = \frac{PV}{100}
\]  

(12)

\[
Power, P = W_o + W_u
\]  

(13)

\[
W_o = CFL(G_g + G_b)\cos\delta + G_{rp} + H(G_g + G_b)
\]  

(14)

\[
W_u = CFL(G_b\cos\delta + G_{ru}) \pm HG_b
\]  

(15)

where, \(W_o\) is the resistance of the belt on the top run; \(W_u\) is the resistance of the belt on the bottom run; C is the coefficient for all-inclusive consideration of secondary resistance (2.25); F is 0.02, the coefficient of friction between the idler and the belt; L is the length of the belt; \(G_g\) is weight of belt per meter length; \(G_b\) is weight per unit length of belt; \(\delta\) is the inclination angle; \(H\) is the height through which material is conveyed and v is the belt speed.

Capacity of the Conveyor, Q:
The capacity of the conveyor was determined as 0.049 kg/s using equation 16 [18]

\[
Q = \frac{0.326 \times \text{Belt Speed} \times \text{Vol. of Belt} \times \text{Density of Material} \times \text{Efficiency}}{\text{Conveying space}}
\]  

(16)

where efficiency varies between 75 and 85%.

2.2.4 The Power Transmission System. The planter is tractor-pulled. Power is transmitted from the tractor through the land wheel of the planter to other components of the planter as required with the aids of chains and sprockets and a pair of spur gears. The power from the land wheel is transmitted to the angle drive (transmission gear) that transmits power at angle to the cutting unit. Power is then transmitted to the second cutting shaft through the pair of spur gears and the power is finally transmitted to the roller-picker through the chain and sprocket.

The design of the chains and sprockets was done according to the methods outlined by PSG TECH [18] and [20].
2.2.5 Furrow opener. Double Disc type furrow opener was chosen for the planter to achieve a low draught requirement and digging efficiency to a depth of 100 mm. Taking into consideration that maximum depth of penetration of a disc is one-third of its diameter [21, 22]), 300 mm was chosen as the diameter of the discs. The discs are plain circular plates cut from a medium carbon steel of 6 mm thickness.

The Discs in operating position and at maximum depth have the draught force per unit width of blade (H) and the vertical force per unit width (V) given by Agbetoye [23]) (Equations 17 and 18) as:

\[
H = P \sin(\alpha + \delta) + C_a \cos\alpha \\
V = P \cos(\alpha + \delta) + C_a \sin\alpha
\]  

(17)

(18)

According to Ashrafizadeh and Kushwaha [24], the passive force per unit width of the tine (P) is given as (Equation 19):

\[
P = \left( \gamma d^2 N_r + C_d N_c + q d N_q \right) w
\]  

(19)

where; C is the soil cohesion (N/m²), C_a is soil adhesion (N/m²), α is the rake angle (°), δ is the soil/metal friction angle (°), γ is the soil density (kg/m³), g is the acceleration due to gravity (m/s²), w is the tool width (m), d is the maximum working depth (m), φ is the angle of shearing resistance (°), N_r, N_c, and N_q are factors read out using identity in equation 20.

\[
N_{r,c,q} = N_{\delta=0} \left( \frac{N_{\delta=0}}{N_{\delta=0}} \right)^{\delta/\phi}
\]  

(20)

For a typical sandy loam soil, as reported by Agbetoye [23], the values of soil mechanical characteristics are as follows; Angle of Shearing Resistance (φ) is 22°; Angle of Soil/Metal Friction (δ) is 10°; Soil Cohesion (C) is 5.2 kN/m²; Soil Adhesion (C_a) is 2.6 kN/m²; Soil Density (ρ) is 1774 kg/m³ and acceleration due to gravity (g) is 9.81 m/s².

2.2.6 Furrow Coverer. Double disc furrow coverer of the same dimensions with the furrow opener and arranged in a reversed direction of the furrow opener was designed for the planter so that it drag to loose soil back to the furrow to cover the stake. It was attached behind the planter in the same direction of the furrow opener.

2.3 Machine Fabrication and Assembly

The planter consists of the hopper, a roller-picker, the cutting unit, metering unit, double-disc furrow opener, double-disc furrow coverer, land-wheels, transmission devices that includes an angle drive, chains and sprockets and a pair of spur gears, three-point linkage and the frame.

The components of the planter were fabricated and assembled at the workshop of Agricultural and Environmental Engineering Department, Federal University of Technology, Akure, Nigeria. The planter consists of the hopper, roller-picker, cutting unit, metering unit, furrow opener, furrow coverer, land wheel power transmission system, instrumentation system, three-point linkage and the frame. The fabrication of the planter was carried according to the design specifications. Marking out of the steels for fabrication was carried out using a steel rule and a scriber. Operations like cutting, drilling, machining and welding were carried using the appropriate machines as available in the workshop. Components of the planter were assembled on the fabricated frame as presented in Figures 2 and 3. The frame is equipped with two land wheels that transmit power from the tractor that serves as the prime mover for the planter.
2.4 Field Test of the Planter

Following the fabrication and assembly of the various components of the single-row planter, a farm land cleared, ploughed and harrowed in preparation for a preliminary test of the planter. The planter was coupled to the three-point linkage of a TAK-100 tractor. It was loaded with cassava stems of TME 419 for planting. The planter was tested by operating it on the prepared clayey-loam soil Akinbamowo et. al. [25] at an operating speed of 2 km/hr along a row of 20 m and soil moisture content of 22.8 %. The planting depth chosen for the test was 100 mm.

The number of stakes planted (Figure 4) were recorded after the planting operation. The field test was repeated two times. During the test, the behavior of the various systems was observed with regard to rotation of the land wheels, opening of the soil by the furrow opener, the stem picking from the hopper, movement of belt conveyor for appropriate placement of the stake, covering of the stakes by the furrow opener. The stakes planted (Figure 5) were later removed from the soil to analyses the percentage of stake damage. The parameters of stem, soil, and machine used for the test are presented in Table 1.

| Parameter              | Value   |
|------------------------|---------|
| Soil Textural Class    | Clay loam |
| Soil Moisture Content  | 22.8%   |
Soil Depth 100 mm
Cassava Variety TME 419
Stem Girth(diameter) 35 mm
Spacing 1 m
Tractor Forward Speed 2km/h
Land Preparation Ploughing and harrowing

3. Results and Discussions

3.1 Result of the Preliminary Test

The result of the preliminary test is shown in Table 2.

| Test | No of Stakes Discharged | No of Stakes Damaged | Functional Efficiency (%) |
|------|-------------------------|----------------------|---------------------------|
| 1    | 8                       | -                    | 100                       |
| 2    | 11                      | 1                    | 90.9                      |
| Average |                       |                      | 95.45                     |

3.2 Discussion

The performance of the planter during the test satisfied the design considerations of the planter as it was able to hold the cassava stems; pick the stems for cutting, cut the stem into stake, convey and place the stakes for planting, open the soil and cover the soil.

Some stakes were not uniformly planted. This is as a result of occurrence of slippage during the preliminary test. The slippage was caused by the nature of the pneumatic wheels selected. To overcome the limitation, rigid wheels will be designed to replace the pneumatic tyres. However, it was reported by Maw et al [26], that such cases are not uncommon with prototype machines under the first field test. According to him it results to better understanding of the machines.

4. Conclusions

The following conclusions have been drawn from this study:

i. A cassava planter has been designed and fabricated.
ii. The designed components have been fabricated and assembled.
iii. The preliminary test of the planter has been conducted.
iv. The preliminary test has revealed that the cassava planter satisfies most of the functional requirements of a planter.

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