Design and Fabrication of a Single Row Maize Planter for Garden Use

Ibukun B. IKECHUKWU¹, Agidi GBABO², Ikechukwu C. UGWUOKE³

¹ ¹Department of Mechanical Engineering, Federal University of Technology, Niger State, Nigeria.
² ²National Cereals Research Institute, Badeggi, Niger State, Nigeria.
³ ³*Corresponding author: Ikechukwu C. UGWUOKE, Department of Mechanical Engineering, Federal University of Technology, PMB 65, Minna, Niger State, Nigeria. E-mail: ugwuoikeichekwu@yahoo.com

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ABSTRACT
This work focused on the design and fabrication of a manually operated single row maize planter capable of delivering seeds precisely in a straight line with uniform depth in the furrow, and with uniform spacing between the seeds. The work demonstrates the application of engineering techniques to reduce human labour specifically in the garden. The results obtained from the trial tests showed that the planter functioned properly as expected with a planting capacity of 0.0486 hectare/hr. Visual inspection of the seeds released from the planter’s metering mechanism showed no visible signs of damage to the seeds.

Keyword: Design, fabrication, manually operated, single row, maize planter.

INTRODUCTION
Maize has been in the diet of Nigerian’s for centuries. It started as a subsistence crop and has gradually become a more important commercial crop [1]. In industrialized countries, maize is largely used as livestock feed and as a raw material for industrial products. Maize is an important source of carbohydrate, protein, iron, vitamin B, and minerals. Africans consume maize as a starch base in a wide variety of porridges, pastes, grits, and beer. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled; playing an important role in filling the hunger gap after the dry season [2]. In Africa, especially in the sub-Saharan Africa countries, the use of hoes and cutlasses for crop cultivation is still prevalent due to abject poverty within the region. A seed planter is simply a device or tool used to sow seeds. In small scale landscaping and gardening, manually operated seed planters can be used, while in large farm cultivations, the planter can be a massive device usually attached to the back of a tractor. Seed planters depend on both human and machine effort for its operation.

Research indicates that most growers could improve their yields by just improving on the planter’s performance [3-5]. This work focused on the design and fabrication of an affordable manually operated single row maize planter specifically for garden use. The design was to improve on seed spacing and depth uniformity in the seed planting process. The benefits of this particular design includes: Increased agricultural output; Reduced production cost, which makes the planter affordable; Makes crop cultivation less laborious; Makes farming more attractive to the youths; Reduces urban migration by youths in search of white collar jobs; Ensures capacity utilization of available farm land; Saves tremendous amount of time during farming.

DESCRIPTION, DESIGN ANALYSIS, AND MATERIAL SELECTION
The function of a well-designed seed planter is to meter seeds of different sizes and shapes, place the seed in the acceptable pattern of distribution in the field, place the seed accurately and uniformly at the desired depth in the soil and cover the seed and compact the soil around it to enhance germination and emergence [6]. The recommended row to row spacing, seed rate, seed to seed spacing and depth of seed placement vary from crop to crop and for different agro-climatic conditions to achieve optimum yields. Seed flow through a planter is dependent on size, shape, sphericity, true density and angle of repose of seeds. In addition, the impact of seeds on the internal components of the planter is influenced by the coefficient of restitution of seeds on various impinging surfaces [7].

Main Frame
The main frame is the skeletal structure of the seed planter on which all other components are mounted. The two design factors considered in the determination of the material required for the frame are the weight and strength. In this work, mild steel angle bar of 50.8mm x 50.8mm and 4mm thickness were used to give the required rigidity.

Adjustable Handle
The handle of the seed planter was designed to be adjustable for the different height of individuals thereby reducing drudgery. The handles help the operator to push the planter while in operation. The material used for the handle was a combination of 1 inch mild steel square pipe, ¼ inch mild steel square pipe, and 1 inch mild...
steel angle bar.

**Seed Hopper**
The seeds container as the name implies is a device in which the seeds to be planted are kept (transitionally) before their gradual release into the furrowed tunnel. The hopper has the shape of a frustum of a pyramid truncated at the top as shown in Figure 1. To ensure free flow of seeds, the slope of the hopper was fixed at 30°, which is modestly higher than the average angle of repose of the seeds. The seed container also has a lid, with a handle on top to ease opening. The material used for the design was 2mm thick mild steel sheet metal.

**Seed Metering Mechanism**
Metering mechanism is the heart of sowing machine and its function is to distribute seeds uniformly at the desired application rates [6]. In planters it also controls seed spacing in a row. A seed planter may be required to drop the seeds at rates varying across wide range [6]. Proper design of the metering device is an essential element for satisfactory performance of the seed planter. The design of the metering device used for this work is the wooden roller type with cells on its periphery. The size and number of cells on the roller depends on the size of seed and desired seed rate. In this design, the wooden roller lifts the seeds in the cells and drops these into the seed funnel which is conveyed to the open furrow through the seed tube. For varying the seed rate and sowing different seeds, three separate rollers were provided. The number of cells on the seed metering device may be obtained from the following expression

\[
\text{Number of cells} = \frac{\pi \times \text{Diameter of the planter’s ground wheel}}{\text{Intra – row spacing of seeds}} \tag{1}
\]

Recommended intra-row spacing for maize are [6]

**Adjustable Furrow Opener**
The design of furrow openers of seed planters varies to suit the soil conditions of particular region. Most seed planters are provided with pointed tool to form a narrow slit in the soil for seed deposition. The adjustable furrow opener permits planting at each variety’s ideal ground depth. The type used for this work is the pointed bar type. These types of furrow openers are used for forming narrow slit under heavy soils for placement of seeds at medium depths. The material used for the design was 50mm x 5mm mild steel flat bar.

**Adjustable Furrow Closer**
The furrow closer was also designed to be adjustable. The type used for this design is the shoe type furrow closer. It was designed to allow for proper covering and compaction of the soil over the seeds in the furrows. The material used for the design was 50mm x 5mm mild steel flat bar.

**Drive Wheel**
The wheels are located at both ends of the frame. They are circular in shape containing 1 inch square pipes which serves as spokes. These spokes are used to support the centre bushing or hub. The spokes are arranged in such a way that it braced the wheels circular circumference and also gives it necessary radial support. Material used for the design was a combination of both 1 inch mild steel square pipes and 3mm thick mild steel flat bars.

**Seed Tube**
This was the channel through which seeds are conveyed to the furrow. The material used was a conical funnel with a rubber hose. The outlet diameter is 1 inch.

**Bearing Selection**
Bearings are selected based on their load carrying capacity, life expectancy and reliability. Ball bearings are fixed in the bushing provided at the two ends of the frame in other to support the eccentric shaft on which the wheels are attached. They allow the carrying of an impressive load without wear and tear and with reduced friction. This device ensures the smooth operation of the wheels. The material for the bearing is high speed steel.

**Determination of the Weight of the Hopper Material**
From Figure 2, using Pythagoras theorem, the length EK is obtained as follows

\[
EK^2 = FL^2 + 0.1^2 + h^2 \tag{2}
\]

\[
EK = FL \sqrt{0.1^2 + h^2} \tag{3}
\]

\[
\text{Area } EAK = \frac{1}{2} \times AK \times FL \tag{4}
\]

\[
\text{Area } EKLF = KL \times FL \tag{5}
\]

\[
\text{Area } EFON = EF \times EN \tag{6}
\]

\[
\text{Area } ABMJ = AB \times BM \tag{7}
\]

\[
A_{HM} \text{ for one side} = 2 \times \frac{1}{2} \times AK \times FL + KL \times FL + EF \times EN + AB \times BM \tag{8}
\]

\[
A_{HM} = 4 \times A_{HM} \text{ for one side of hopper material} \tag{9}
\]

\[
V_{HM} = A_{HM} \times t_{HM} \tag{10}
\]

\[
M_{HM} = V_{HM} \times \rho_{HM} \tag{11}
\]

\[
W_{HM} = M_{HM} \times \text{Acceleration due to gravity} \tag{12}
\]

Where,

- \( A_{HM} \) = Surface area of the hopper material
- \( V_{HM} \) = Volume of the hopper material
- \( t_{HM} \) = Thickness of the hopper material

![Figure 1: Diagram of the hopper in its inverted form](image)

![Figure 2: Diagram showing one part of the hopper in its inverted form](image)
\[ M_{HM} = \text{Mass of the hopper material} \]
\[ \rho_{HM} = \text{Density of the hopper material} \]
\[ W_{HM} = \text{Weight of the hopper material} \]

From computations, the weight of the hopper material \( W_{HM} = 112 \text{N} \)

**Determination of the Weight of the Main Frame Material**

From Figure 3, the weight of the main frame material may be obtained from the following expressions

\[ A_{MFM} = \left[w_{MFM} + (w_{MFM} - t_{MFM})\right](6 \times L + 4 \times l) \quad (13) \]
\[ V_{MFM} = A_{MFM} \times t_{MFM} \quad (14) \]
\[ M_{MFM} = V_{MFM} \times \rho_{MFM} \quad (15) \]
\[ W_{MFM} = M_{MFM} \times \text{Acceleration due to gravity} \quad (16) \]

Where,
\[ A_{MFM} = \text{Surface area of the main frame material} \]
\[ w_{MFM} = \text{Width of the main frame material} \]
\[ V_{MFM} = \text{Volume of the main frame material} \]
\[ t_{MFM} = \text{Thickness of the main frame material} \]
\[ M_{MFM} = \text{Mass of the main frame material} \]
\[ \rho_{MFM} = \text{Density of the main frame material} \]
\[ W_{MFM} = \text{Weight of the main frame material} \]

**Determination of the Weight of Grain**

From Figure 4, using Pythagoras theorem, the lengths \( QG \) and \( AC \) are determined as follows

\[ EG^2 = EF^2 + FG^2 \quad (17) \]
\[ EG = \sqrt{EF^2 + FG^2} \quad (18) \]
\[ QG = \frac{1}{2}EG = \frac{1}{2}\sqrt{EF^2 + FG^2} \quad (19) \]
\[ AC^2 = AB^2 + BC^2 \quad (20) \]
\[ AC = \sqrt{AB^2 + BC^2} \quad (21) \]
\[ RC = \frac{1}{2}AC = \frac{1}{2}\sqrt{AB^2 + BC^2} \quad (22) \]

\[ H - h = QG \times \frac{H}{RC} \quad (25) \]
\[ H\left(1 - \frac{QG}{RC}\right) = h \quad (26) \]
\[ H = \frac{h}{\left(1 - \frac{QG}{RC}\right)} \quad (28) \]

The volume of the hopper may be obtained from the following expression

\[ V_H = \frac{1}{3}[\text{area of truncated frustum base} \times \text{height of truncated frustum} - \frac{1}{3}[\text{area of frustum base} \times \text{overall height of frustum}] + \text{volume of the square extension at the top and bottom of hopper} - \frac{1}{3}[(AB \times BC)(H - (EF + FG)(H - h)) + \frac{1}{2}(AB \times BC) + (EF \times FG)] \times 0.05 \quad (29) \]

\[ M_G = V_H \times \rho_G \quad (30) \]
\[ W_G = M_G \times \text{Acceleration due to gravity} \quad (31) \]

Where,
\[ V_H = \text{Volume of hopper} \]
\[ M_G = \text{Mass of grain} \]
\[ \rho_G = \text{Density of grain} \]
\[ W_G = \text{Weight of grain} \]

From computations, the weight of the grain \( W_G = 204 \text{N} \)

**Determination of the Maximum Bending Moment**

Figure 5 shows the load distribution on the shaft. The maximum bending moment may be determined from the following expressions

\[ R_1 + R_2 = 2 \times \frac{1}{2}(W_{MFM} + W_{HM} + W_{GRH}) + W_{GRS} \quad (32) \]
\[ R_1 = \frac{1}{2}\left[\frac{1}{2}(W_{MFM} + W_{HM} + W_{GRH}) \times 0.45 + W_{GRS} \times 0.25 + \frac{1}{2}(W_{MFM} + W_{HM} + W_{GRH}) \times 0.05\right] \]
Where,
R_i, R_2 = Reactions at the support
W_{GRH} = Weight of grain resting on the hopper
W_{GRS} = Weight of grain resting on the shaft

Using the method of sectioning, the following expressions were obtained for the bending moment

\[ M_{b1} = R_1 \times 0.05 \]  
\[ M_{b2} = R_1 \times 0.25 - \frac{1}{2}(W_{MFM} + W_{IM} + W_{GRH}) \times 0.2 \]  
\[ M_{b3} = R_1 \times 0.45 - \frac{1}{2}(W_{MFM} + W_{IM} + W_{GRH}) \times 0.4 - W_{GRS} \times 0.2 \]  

The maximum value in equation (36), (37), and (38) is taken as the maximum bending moment for the shaft.

\[ V_{GRS} = 0.45 \times (E \times F \times G) \]  
\[ M_{GRS} = V_{GRS} \times \rho_G \]  
\[ W_{GRS} = M_{GRS} \times \text{Acceleration due to gravity} \]  
\[ W_{GRH} = W_G - W_{GRS} \]  

Where,
V_{GRS} = Volume of grain resting on the shaft
M_{GRS} = Mass of grain resting on the shaft

From computations, the maximum bending moment \( M_b = M_{b3} = 12.91 \text{Nm} \)

**Determination of the Shaft Diameter**

Shaft design consists primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions. Design of shafts of ductile material based on strength is controlled by maximum shear theory. The material for the shaft is mild steel rod. For a shaft having little or no axial loading, the diameter may be obtained using the ASME code equation [9] given as

\[ d^3 = \frac{16}{\pi S_a} \sqrt{(k_b M_b)^2 + (k_t M_t)^2} \]  

Where,
d = Diameter of the shaft
M_b = Bending moment
M_t = Torsional moment
k_b = Combined shock and fatigue factor applied to bending moment
k_t = Combined shock and fatigue factor applied to torsional moment

For rotating shafts, when load is suddenly applied (minor shock) [9]:

\[ k_b = 1.5 \text{ to } 2.0 \quad k_t = 1.0 \text{ to } 1.5 \]  

For shaft without key way, allowable stress \( S_a = 55 \text{MN/m}^2 \)

For shaft with key way, allowable stress \( S_a = 40 \text{MN/m}^2 \)

From computations, the diameter of shaft \( d = 14.87 \text{mm} \)

**Determination of the Planter Push Force**

Figure 6 gives the free body diagram showing all the forces acting on the planter. The force required to push the planter may be obtained from the following expressions

\[ F_x = F_P \cos \theta - R_S \cos \phi - F_R = 0 \]  
\[ F_y = R_S \sin \phi - F_P \sin \theta - W_P = 0 \]  

Where,
F_P = Planter push force
F_R = Horizontal soil resistance force
R_S = Soil frictional resistance force
\( \phi \) = Angle of friction
\( \theta \) = Angle between planter handle and the horizontal plane
W_P = Weight of planter

\[ r \sin \phi \]  
\[ r \cos \phi \]  
\[ F_P \cos \theta \]  
\[ F_P \sin \theta \]  

From equation (43)

\[ F_P = \frac{R_S \cos \phi + F_R}{\cos \theta} \]  

Substituting equation (45) into equation (44), we get

\[ R_S = \frac{F_R \tan \theta + W_P}{\sin \phi - \cos \phi \tan \theta} \]  

**Determination of the Maximum Draft on the Planter**

The maximum draft on the planter is a function of the soils resistance on the machine and the area of contact of the furrow opener with the soil. The maximum draft on the planter is the horizontal component of push parallel to the line of motion in order to overcome the soil resistance on the planter [8]. The maximum draft may therefore be obtained from the following expression

\[ D_{FM} = R_S \times A_{FO} \times \text{Acceleration due to gravity} \]
Surface area of furrow opener in contact with soil (48)

For sandy soil, \( D_{PM} = 0.210kg/cm^2 \times 5.250cm^2 \times 9.81m/s^2 = 10.186N \)

For sandy moist soil, \( D_{PM} = 0.245kg/cm^2 \times 5.250cm^2 \times 9.81m/s^2 = 12.618N \)

For sandy loam dry soil, \( D_{PM} = 0.315kg/cm^2 \times 5.250cm^2 \times 9.81m/s^2 = 16.223N \)

For silt moist soil, \( D_{PM} = 0.385kg/cm^2 \times 5.250cm^2 \times 9.81m/s^2 = 19.828N \)

For silt dry soil, \( D_{PM} = 0.455kg/cm^2 \times 5.250cm^2 \times 9.81m/s^2 = 23.434N \)

For clay moist soil, \( D_{PM} = 0.525kg/cm^2 \times 5.250cm^2 \times 9.81m/s^2 = 27.039N \)

For clay dry soil, \( D_{PM} = 0.665kg/cm^2 \times 5.250cm^2 \times 9.81m/s^2 = 34.249N \)

For heavy clay dry soil, \( D_{PM} = 0.735kg/cm^2 \times 5.250cm^2 \times 9.81m/s^2 = 37.854N \)

Determination of Planter Capacity

The capacity of the planter may be determined in terms of the area of land covered per time during planting or the number of seeds planted per time of planting. The capacity of the planter in terms of number of seeds planted per time may be obtained from the following expression

\[
C_{PN} = \frac{Area\ covered\ by\ planter}{10000m^2} \times \text{Number\ of\ seeds\ per\ hole} \quad (52)
\]

The speed of the planter may be obtained from raw experiment. The capacity of the planter for maize is therefore obtained as follows:

\[
C_{PM} = \frac{Area\ covered\ by\ planter\ for\ maize\ in \ m^2/\ time}{10000m^2/\ hectare} \times \frac{10000m^2/\ hectare}{540m/\ hr} \times \frac{2\ seeds}{1\ seed\ tube} \times \frac{10000\ seeds/\ hr}{60\ mins/\ hr} = \frac{486m^2/\ hr}{10000m^2/\ hectare} = 0.0486\ hectares/\ hr
\]

The time required to cultivate 1 hectare of land is therefore obtained as follows

\[
Time\ required\ = \frac{1}{0.0486} = 20.576hrs
\]

Number of days required to plant on a hectare of land

Assuming 8hrs is used per day for planting, the number of days required to plant on 1 hectare of land is obtained as follows

\[
\frac{20.576hrs}{8hrs/\ day} = 2.572\ days \approx 2.6\ days
\]
0.15 m/s, the pointed bar type furrow opener penetrated the soil creating a furrow for seeds to be placed. The planter’s ground wheel is connected directly to the seed metering device, and as the ground wheel rotates, the seed metering device placed at the bottom of the hopper also rotates, thereby releasing two or three seeds depending upon the size of the cells or the size of the seeds. These seeds are then conveyed to the furrow through the seed tube. The furrow was then closed by the shoe type furrow closer. A close visual inspection of the seeds that were released from the planter’s metering mechanism shows no visible sign of damage.

CONCLUSION

This work focused on the design and fabrication of a manually operated single-row maize planter that is cheap, easily affordable, easy to maintain and less laborious to use. The planter will go a long way in making farming more attractive and increasing agricultural output. All parts of the planter were fabricated from mild steel material, except for the metering mechanism which was made from good quality wood (mahogany) and the seed funnel and tube, which were made from rubber material. The seed metering mechanism used for this work was the wooden roller type with cells on its periphery. For this design, the drive shaft directly controls the seed metering mechanism which eliminates completely attachments such as pulleys, belt systems, and gears thereby eliminating complexities which increase cost, and increasing efficiency at a highly reduced cost. The results obtained from the trial tests showed that the planter functioned properly as expected with a planting capacity of 0.0486 hectare/hr.

REFERENCES
