Development and Testing of a Manually Operated Single-Row Maize Planter

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Abstract

In this study, a manually operated single row maize planter was developed and tested. Parts such as the mainframe, maize hopper, maize metering mechanism, shaft, and seed tube were designed. From the field tests, it was observed that there was a reasonable deviation of the experimented seed spacing from the designed seed spacing, this was as attributed to the speed of the human pushing the seed planter which was 0.83m/s. Also, the experimental results showed that the majority of the holes contained 2 seeds while the least contained 5 seeds. Also, from the experimental results, the seed planter has a seed rate per hectare of $73{,}162.84 seed\ rate/hectare$, and the weight of maize grain required per hectare as $21.82 kg/hectare$ which is between the specified seed planter accepted range by Information and Communication Support for Agricultural Growth.

Keywords: Maize, Manual Planter, Single-row, Agriculture

1. Introduction

The need for developing and underdeveloped countries to feed themselves rather than depend on the importation of food has been the priority of the successive governments of these countries. This need has been articulated through the concept of "Operation Feed the Nation" (OFN) programmed (1977) and the "Green revolution" programmed (1980) in Nigeria amongst other programs. These programs were aimed at encouraging local agricultural production. The traditional Farmers in developing and underdeveloped countries today are in the majority. Farmers seem to have no access to credit facilities, and cannot afford to buy or hire the agricultural machinery to enhance their farming capabilities [1].

The traditional method farming in these countries is majorly labour intensive and although, some of the farmers can afford the services of animal-drawn implements for the ploughing of land because this method of mechanized tilling of the land can be used to cultivate large farmland more than the traditional use of hands and local hoes. The use of animal-drawn farming is an improved method of cultivation that has been implemented to eliminate the physical exhaustion attached with manual traditional method of farming and this method has also been stretched to seed planting. The mechanized seed planting methods which involve the use of tractors are quite expensive and unaffordable for the majority of the traditional farmers [1].

Using the manually cultivated method for planting maize seeds showed that sown seeds per hill are more than the prescribed amount. This results in overpopulation and consequently reduce yield due to insect build-up and nutrients and sunlight competition. This method of maize cultivation also requires a lot of labour and time. Farmers practice broadcast sowing of maize which costs less, but final income is also less due to increased plant population rate, higher seed cost, increase intercultural operational cost, and lower grain yields. Few farmers practice labour intensive line sowing methods with higher labour cost which also encourages the introduction of maize planters [2].

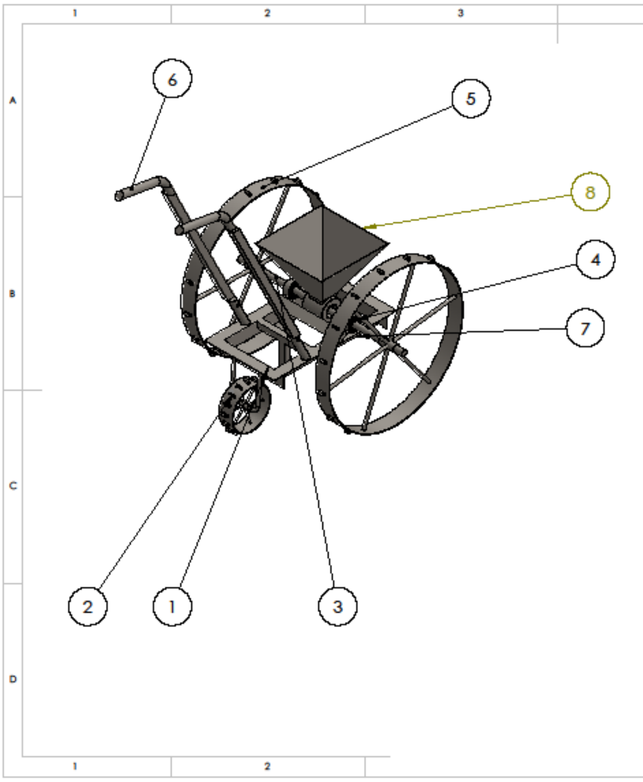
It has been discovered that the manual method of seed planting results in poor seed placement, inefficient spacing, and ergonomic issues for the farmer such as backache for which limits the capacity of the field that can be planted [3]. Also, planting machines or planters that are can eliminate some of these problems and increase productivity are usually beyond the buying capacity of smallholder farmers [1]. Hence, this work focus on the development and testing of an affordable manually operated single metering device maize planter

2. Description of the Machine Component.

The maize planter design is made up of the following major parts.

i. **Main Frame:** This is the skeletal structure of the maize planter on which all other components are mounted. It is made of mild steel
ii. **Handle:** This was designed to be adjustable for the different height of individuals to reduce drudgery. The handle helped the operator to push the planter while in operation.
iii. **Maize hopper:** This helps to hold the seeds to be planted before their gradual release into the furrowed tunnel.
iv. **Maize Metering Mechanism:** This was used to distribute maize uniformly at the desired application rates. It is of wooden roller type with cells on its periphery. 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.
v. **Furrow Opener:** This permitted planting at ideal ground depth. It is of pointed bar type capable of forming narrow slit under heavy soils for placement of maize at medium depths.
vi. **Furrow Closer:** This was designed to allow proper covering and compaction of the soil over the maize in the furrows.
vii. **Drive Wheels:** These are located at both ends of the frame. They are circular.
viii. **Seed Tube:** This was the channel through which maize seeds are conveyed to the furrow.
ix. **Bearing Selection:** Bearings were selected based on their load-carrying capacity, life expectancy, and reliability. Ball bearings were 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.
x. **Shaft:** The shaft performs both the translational motion of the wheels and the turning of the metering mechanism via two bearings

The seed planter is shown below:



ITEM NO.	PART NUMBER	QTY.
1	Frame	1
2	Small wheel	1
3	Shaft	1
4	Bearing	2
5	Big Wheel	2
6	Handle	1
7	Furrow	2
8	Hopper	1

Figure 1: Assembled seed planter

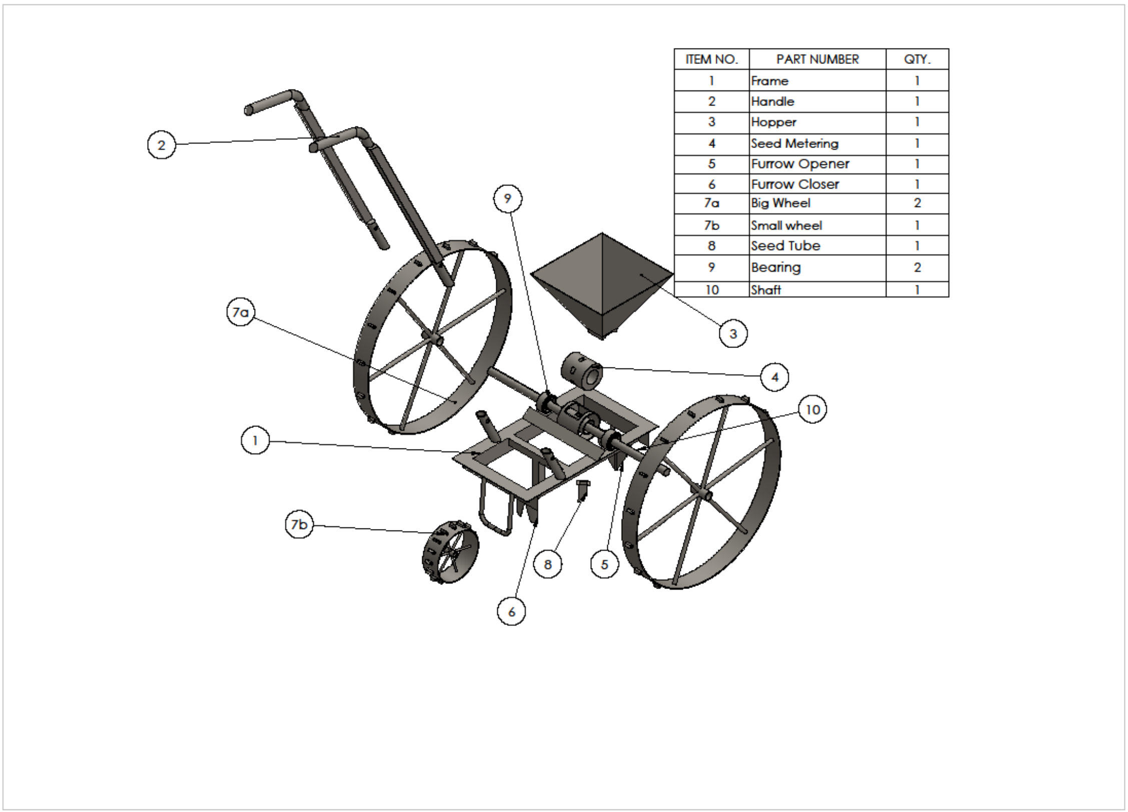


Figure 2: Diagram of the seed planters showing all the necessary parts.

3. Principle of Operation

The selection of materials and methods of construction of a single row maize planter was based on the preliminary investigation.

The hopper was filled with 6kg maize. The filling of the hopper depends on how many areas of the field to be covered. As the maize planter was pushed forward in the direction of travel, the pointed bar type furrow opener penetrated the soil creating a furrow for seeds to be placed. The planter's ground wheel was connected directly to the seed metering device, and as the ground wheel rotates, the maize metering device place at the bottom of the hopper also rotates, thereby releasing two or three maize depending upon the size of the maize seed. These maize seeds were then conveyed to the furrow through the seed tube. The furrow closer then covers the maize seed.

4. Design Analysis

The following design analysis was carried out to select the various machine parts:

1. Determination of the Weight of the Hopper

The weight of the hopper is essential in the determination of the power required to move and operate the planter and is given as

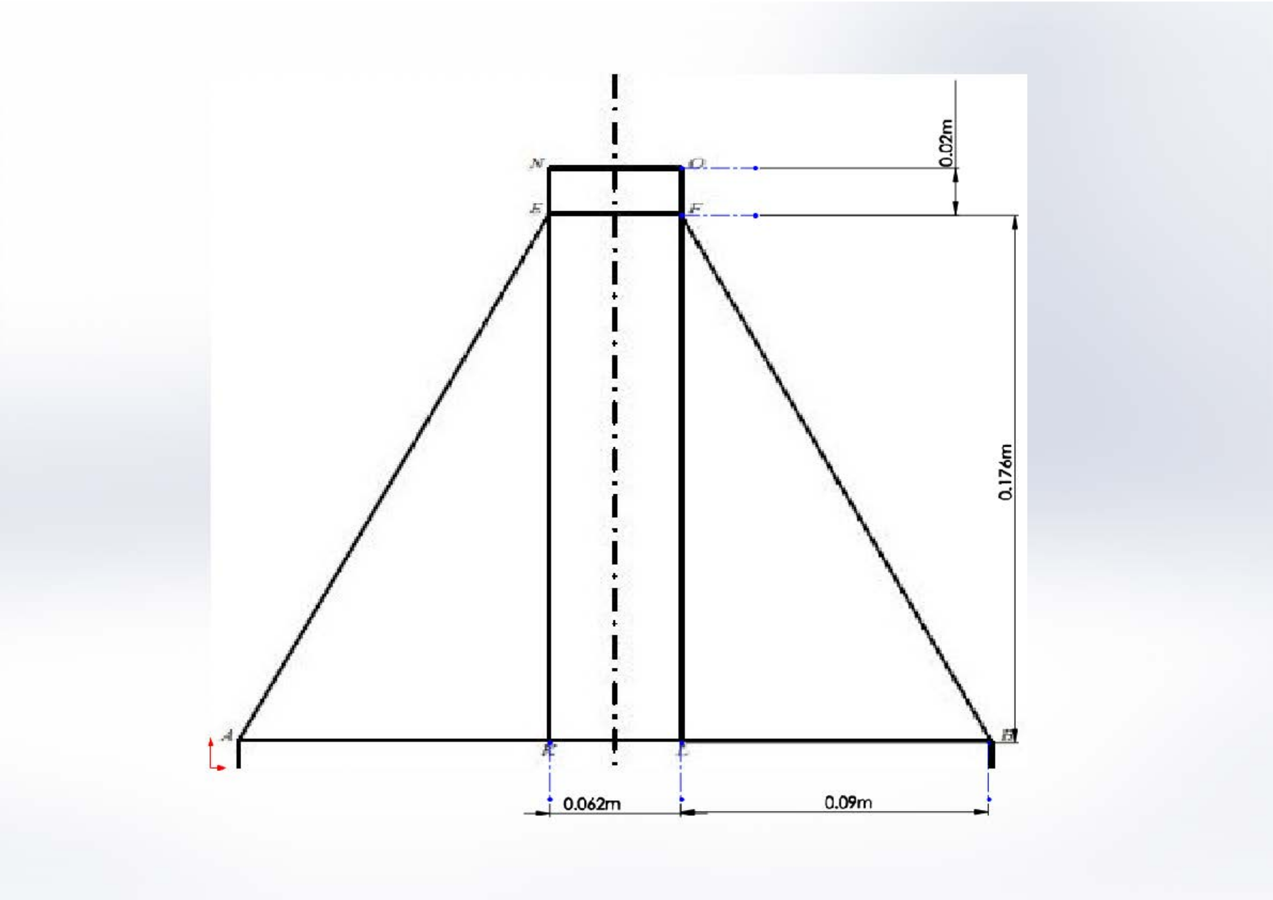


Figure 3: Hopper dimension

$$A_{HM1} = 2(LB * FL) + (KL * FL) + (EF * EN) \quad (1)$$

$$A_{HM} = 4 * A_{HM1} \quad (2)$$

$$W_H = M_H * g \quad (3)$$

$$\Longrightarrow W_H = V_H * \rho_{HM} * g \quad (4)$$

$$\Longrightarrow W_H = A_{HM} * t_H * \rho_{HM} * g \quad (5)$$

Where, A_{HM1} is the area of one side, W_H is the weight of the hopper, M_H is the mass of the hopper, A_H is the surface area of the hopper, V_H is the volume of the hopper, t_H is the thickness of the hopper, ρ_{HM} is the density of the hopper material and g is the acceleration dues to gravity.

2. Determination of the Weight of the Main Frame

The weight of the frame is essential in the determination of power required to move and operate the machine and using the conventional method of weight and mass determination given as

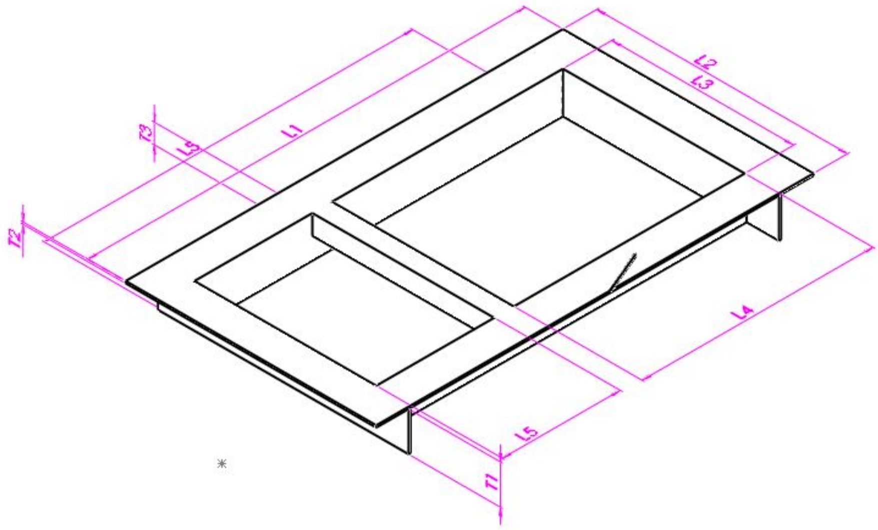


Figure 4: Frame of the seed planter

$$A_{MF} = 2[(L1 * L2) - (L3 * L5) - (L3 * L4)] + (4L1 * T2) + (4L2 * T2) \quad (6)$$

$$W_{MF} = M_{MF} * g \quad (7)$$

$$\Longrightarrow W_{MF} = V_{MF} * \rho_{MF} * g \quad (8)$$

$$\Longrightarrow W_F = A_{MF} * t_{MF} * \rho_{MFM} * g \quad (9)$$

Where, A_{MF} is the Surface area of the mainframe, V_{MF} is the Volume of the mainframe, t_{MF} is the Thickness of the mainframe material, M_{MF} is the Mass of the mainframe, ρ_{MFM} is the Density of the mainframe material, W_{MF} is the Weight of the mainframe and g is the acceleration due to gravity

3. Determination of the Force Required Pushing the Planter

The force required to push the planter may be obtained from the following expressions:

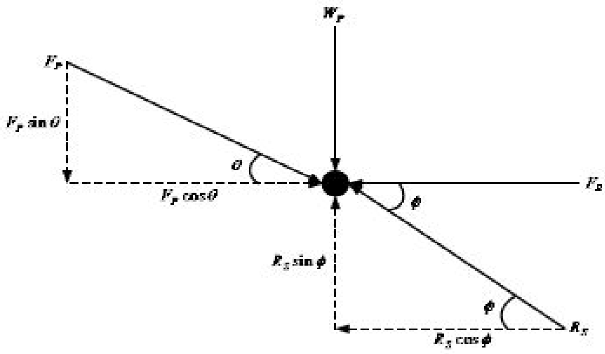


Figure 5: Force on the handle of the seed planter

$$\sum F_x = F_p cos\theta - R_s cos\varphi - F_R = 0 \quad (10)$$

$$\sum F_y = R_s sin\varphi - F_p sin\theta - W_p = 0 \quad (11)$$

Where, F_p is the Planter push force, F_R is the Horizontal soil resistance force, R_s is the Soil frictional resistance force, φ is the Angle of friction which is taken as 45^0 [4], θ is the Angle between planter handle and the horizontal plane which is taken as 40^o [4], W_p is the Weight of planter which is determined using the SolidWorks application.

From equations (10) and (11),

$$F_p = \frac{R_s cos\varphi + F_R}{cos\theta} \quad (12)$$

Substituting equation (12) into equation (10), then

$$F_R = \frac{R_s(sin\varphi - cos\varphi tan\theta) - W_p}{tan\theta} \quad (13)$$

The maximum draft on the planter is a function of the soil's 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 the push parallel to the line of motion to overcome the soil resistance on the planter. The maximum draft may, therefore, be obtained from the following expression

$$D_{FM} = R_s * A_{FO} * g \quad (14)$$

Where, D_{FM} is the Maximum draft, A_{FO} is the Surface area of furrow opener in contact with soil in which $A_{FO} = Depth\ of\ cut * Thickness\ of\ furrow\ open$, and g is the Acceleration due to gravity. The depth of the cut is recommended to be 7cm [5].

4. Determination of the Maximum Twisting Moment

The maximum twisting moment is determined by the following expressions.

$$P = F_p * v \quad (15)$$

Where P is the Power required to push the planter, v is the velocity of the pusher which is assumed to be 0.83m/s [5].

$$M_T = \frac{60*P}{2\pi N} \quad (16)$$

Where N is the revolution of the shaft and this is similar to the revolution of the wheel and this is given as

$$N = \frac{60v}{\pi D} \quad (17)$$

Where D is the wheel diameter.

5. Determination of the Maximum Bending Moment

The maximum bending moment will the obtained from the following expressions

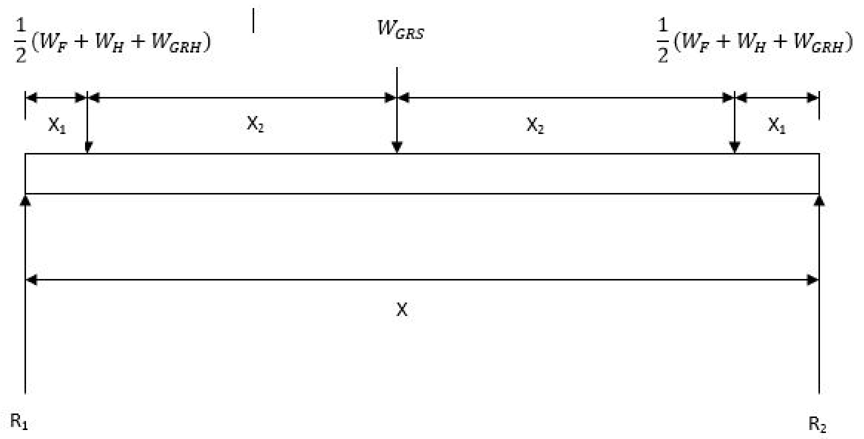


Figure 6: Load Distribution on the shaft

$$R_1 + R_2 = (W_F + W_H + W_{GRH}) + W_{GRS} \quad (18)$$

The method of sectioning is used to obtain the Bending Moments on the shaft,

$$M_{b1} = R_1 * X_1 \quad (19)$$

$$M_{b2} = R_1 * (X_1 + X_2) - \frac{1}{2}(W_F + W_H + W_{GRH})X_2 \quad (20)$$

$$M_{b3} = R_1 * (X_1 + 2X_2) - \frac{1}{2}(W_F + W_H + W_{GRH}) * 2X_2 - W_{GRS} * X_2. \quad (21)$$

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

The maximum value in equation (19), (20), and (21) is taken as the maximum bending moment for the shaft.

Where, W_{GRS} is the weight of grain resting on the shaft, such that $W_{GRS} = V_{GRS} * \rho_G * g$, V_{GRS} is the Volume of the grain resting on the shaft, ρ_G is the density of the grain.

$W_{GRH}$is the weight of the grain resting on the hopper, such that $W_{GRH} = W_G - W_{GRS}$, W_G is the weight of the grain [5]. Also, $X_1 = 0.14m$, $X_2 = 0.11m$

6. Determination of the Shaft Diameter

Shaft design consisted primarily of the determination of the correct shaft diameter to ensure satisfactory strength and rigidity when the shaft transmitted power under various operating and loading conditions. The material for the shaft was a mild steel rod. For a shaft having little or no axial loading, the minimum diameter may be obtained using the ASME code equation (Khurmi and Gupta, 2005) given as

$$d^3 = \frac{16}{\pi S_a}\sqrt{(K_b * M_b)^2 + (K_t * M_t)^2} \quad (22)$$

Where, d is the Diameter of the shaft, M_b is the Bending moment, M_t is the torsional moment, K_b is the Combined shock and fatigue factor applied to the bending moment, $K_t$is the Combined shock and fatigue factor applied to torsional moment and S_a is the Allowable stress

For rotating shafts, when the load is suddenly applied (minor shock), K_b is 1.5 *to* 2.0, K_t is 1.0 *to* 1.5 and for shaft without keyway, allowable stress $S_a = 55MN/m^2$ and for shaft with keyway, allowable stress $S_a = 40MN/m^2$ (Khurmi and Gupta, 2005).

7. 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 the area of land covered per time may be obtained from the following expression

$$C_{PA} = \frac{Area\ covered\ by\ planter}{1000m^2 * time\ of\ planting}(hecter/time) \quad (23)$$

Where,

$$Area\ covered\ by\ planter)(m^2) = (inter\ row\ spacing) * (distance\ coverd\ by\ planter) \quad (24)$$

$$Distance\ covered\ by\ planter(m) = (speed\ of\ planter) * (time\ of\ planting) \quad (25)$$

Where, C_{PA} is the capacity of the planter in$(hecter/time)$.

8. Determination of Seed Cells Size

Some of the criteria that were considered in the selection of cells for the seed metering device were:

- The clearance to enable the metering device to accommodate the designed number of seeds. This was chosen to be 1mm
- The average size of the maize grains was found to be 10.36mm.
- The maize grains can use any of its three-dimensional sides to occupy the holes. The cell diameter is, therefore,

$$Average\ length + clearance = Cell\ diameter \quad (26)$$

5. Results and Discussion

Seed Drop per Hole and Seed Spacing.

In this test, the hopper was filled with 6kg of dried maize seed, and the machine was run through a distance of 23.1m at a speed of about 0.83m/s in the forward direction, the spacing between the seed drops and the numbers of seed drops were obtained.

The number of seed drop per hole on the field and the spacing between the seeds were observed for the 15 revolutions of the wheel and the number of seeds in each hole and the speed spacing and its deviation from the designed seed spacing of 25cm where noted as shown below:

Table 1: Test results of the field performance test to determine the seed spacing and seed drop per hole

S/No	Seed Spacing(cm)	Seed drop/hole
1	28	2
2	29	2
3	30	4
4	30	1
5	40	1
6	32	3
7	34	4
8	29	1
9	28	5
10	26	3
11	39	2
12	35	1
13	35	2
14	24	2
15	25	3
16	28	2
17	28	3
18	26	3
19	33	3
20	22	2
21	25	3
22	30	4
23	38	3
24	40	2
25	28	2
26	26	2
27	39	3
28	36	3
29	23	4
30	39	1
31	34	2

32	26	2
33	28	2
34	28	5
35	26	3
36	39	2
37	35	1
38	24	2
39	25	3
40	28	2
41	28	3
42	29	2
43	30	3
44	30	1
45	40	1
		110

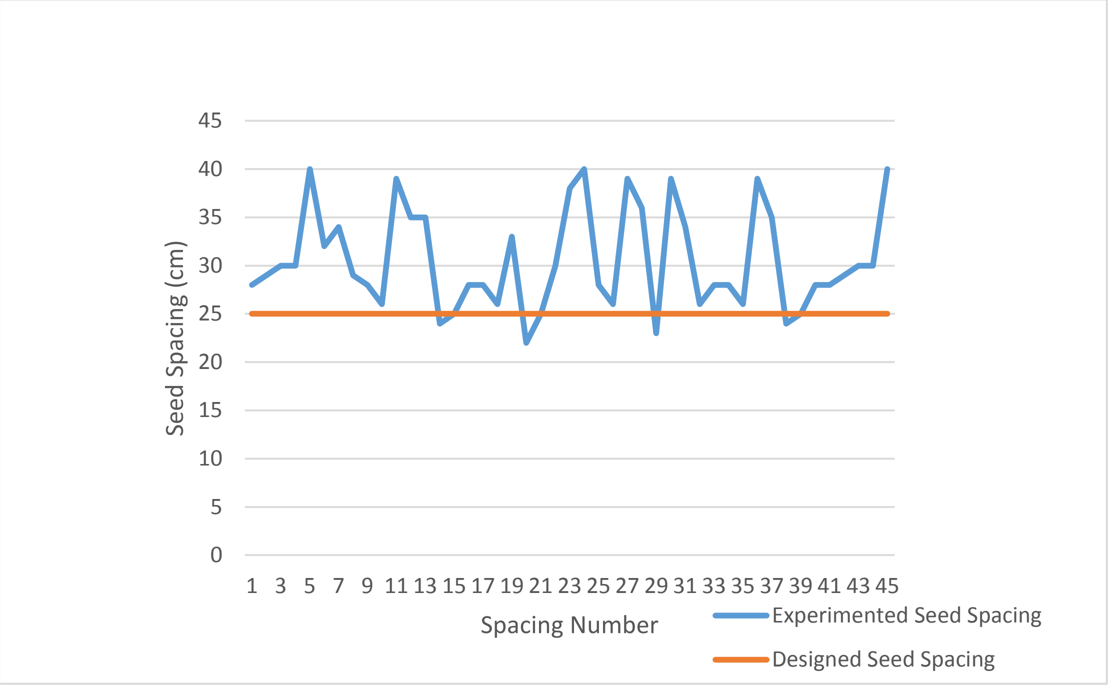


Figure 7: Graph of deviation of the experimented seed spacing from the designed seed spacing of 25cm

It was observed that there is a reasonable deviation of the experimented seed spacing from the designed seed spacing, this was as a result of the speed of the human pushing the seed planter. Therefore, it is recommended that the speed of running the seed planter be reduced to obtain the desired spacing.

Table 2: Table showing the frequency of the seeds in the holes

Number of seeds/ holes	Frequency	Percentage (%)
1	8	17.8
2	17	37.8
3	14	31.1
4	4	8.9
5	2	4.4

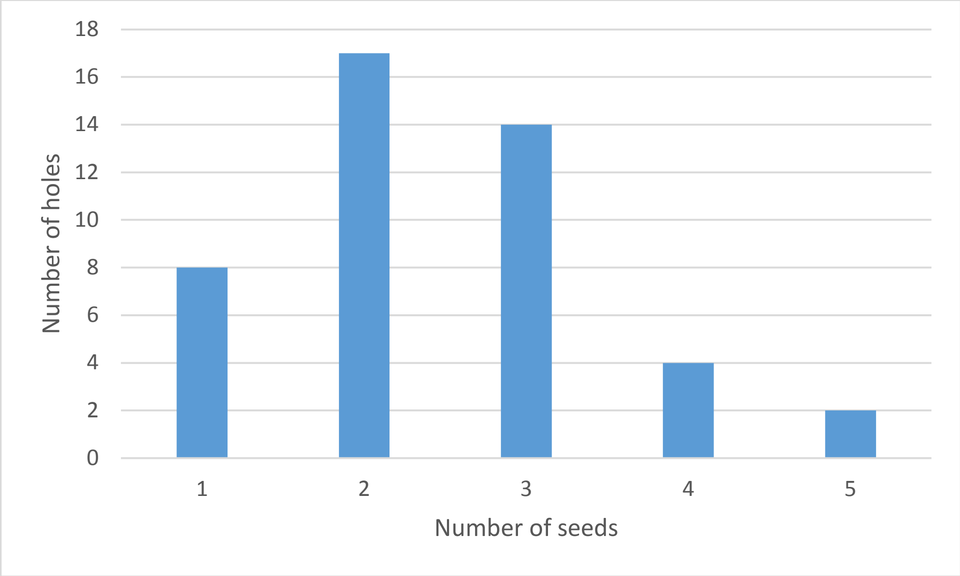


Figure 8: Bar chart of the number of seeds per holes of the field test.

Similarly, it was also observed that the majority of the holes (making up 37.8% of the holes) contained 2 seeds while the least holes (making up 4.4% of the holes) contained 5 seeds

Seed Rate per Hectare

Seed rate per hectare test was performed to ensure the normal density of sprouts and maximum yield. The seeding rate is expressed by the number of germinating seeds per hectare. This test was performed by placing the planter machine at a height with a bag underneath the seed tube to collect the seed droppings as the drive wheel makes 15 revolutions. The distance covered by the drive wheel was calculated and the number of seed drops on the bag was obtained.

$$Seed\ drops\ per\ 15\ revolutions = 110 seeds$$

$$\Longrightarrow Seed\ drops\ per\ revolution = \frac{110}{15} = 7.33 seeds/rev$$

$$Distance\ covered\ by\ 15\ revolutions = 23.1m$$

$$Row\ Spacing = 0.65m$$

$$Area\ of\ an\ hectare = 10{,}000m^2$$

$$Distance\ run\ by\ the\ machine = \frac{10000}{0.65} = 15{,}365m$$

$$Number\ of\ wheel\ revolution\ to\ cover\ an\ hectare = \frac{15 * 15365}{23.1} = 9981.3 rev/hectare$$

$$Seed\ rate\ per\ hectare = 9981.3 * 7.33 = 73{,}162.84 seeds/hectare$$

The average weight of maize grain is $2.982*10^{-4}$kg [6], hence the weight of grain to be used per hectare can be determined,

$$Weight\ of\ grain\ per\ hectare = Seed\ rate\ per\ hectare * Average\ weight\ of\ a\ grain$$
$$= 73{,}162.84 * 2.982 * 10^{-4} = 21.82kg/hectare$$

This test shows that the seed planter has a seed rate per hectare of73,162.84, and the weight of maize grain required per hectare was found to be $21.82kg/hectare$

6. Conclusion and Recommendation

In accordance with the aim of this study, the manually operated single-row maize planter was developed and evaluated using the field tests, the following conclusions were obtained:

- There is a reasonable deviation of the experimented seed spacing from the designed seed spacing, this was as attributed to the speed of the human pushing the seed planter. Therefore, it is recommended that the speed of running the seed planter be reduced to obtain the desired spacing.
- The majority of the holes (making up 37.8% of the experimented holes) contained 2 seeds while the least (making up 4.4% of the experimented holes) contained 5 seeds
- The seed planter has a seed rate per hectare of $73{,}162.84 seed\ rate/hectare$, and the weight of maize grain required per hectare was found to be $21.82 kg/hectare$ which is between the specified seed planter range

The following are recommended for further study and modifications

i. Pressure pump tires should be incorporated and used to replace the metallic wheel to reduce the pushing force, which in turn reduce the strain on the farmer
ii. Cheap and readily available powering systems can be incorporated so as reduce human labour and increase productivity.
iii. Polymeric materials can be used in the design of the metering device as well.

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