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DEVELOPMENT OF A SELF-PROPELLED MULTI-CROP TWO ROWS PRECISION PLANTER: A NEW DESIGN CONCEPT FOR THE METERING MECHANISM

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ABSTRACT

Seed planting is a major step in crop production stages that requires timeliness of operation. It is tedious, less efficient and time-consuming especially when done manually. In this research, a motorized self-propelled multi-crop precision planter with new metering mechanism design concept was developed to address the constraints associated with the manual forms of seed planting using locally available materials. The planter was designed to drop a precise number of seeds at regular intervals mainly for maize, cowpea, and soybean. The machine was evaluated based on performance in the field for its field efficiency, field capacity and percentage of seed damage during operation. Performance evaluation was carried out on a sandy loam soil at the Landmark University Teaching and Research Farm using a 2.2 kW petrol engine as the prime mover. The investigations involved three levels of speed of 4.10, 6.14, and 8.25 km/hr in order to establish the best working speed for the machine. Results obtained showed that the speed of operation has an effect on the performance indices investigated. Best field performance of the planter was obtained at 8.25 km/hr working speed with a field efficiency of 81.2%, minimal seed damage and field capacity of 0.1 ha/hr. The planter was able to correct the problems associated with the manual methods of seed planting such as poor seed placement, poor spacing efficiency, and serious farm drudgery.

Keywords: sowing, grains, precision planter, operating speed, performance indices
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1. INTRODUCTION

Planting is a process of placing seeds in the soil to have good germination. It is one of the most important cultural practices associated with crop production. An exercise which should result in plant stands at the desired density that emerges quickly and uniformly. A good seed planting gives the correct amount of seed per unit area, correct depth at which seed is placed in the soil and correct spacing between row-to-row and plant-to-plant. This is a key factor for efficient harvesting in a mechanized establishment. The seed to seed spacing is mainly dependent on the type of crop and the agro-climate conditions needed to achieve optimum yield [1-4]. Uniform seed distribution within the soil results in better germination and emergence increased yield by minimizing competition between plants for available resources such as light, water, and nutrients. A number of factors affect seed distribution in soil such as the seed metering system, seed delivery tube, furrow opener design, physical attributes of seed, and soil conditions [5].

Seed sowing is a labour intensive exercise, especially when done manually. Hence the needs to mechanize the process become necessary for efficient operation and increase output. In any agricultural operation, timeliness of operations is one of the most important factors which can only be achieved if an appropriate machine is engaged [2]. Seed planting in most farm establishments in Nigeria is usually done manually. A very slow, tedious, time-consuming and expensive exercise that often results in poor seed placement and spacing efficiency, farm drudgery with attendant low yield and productivity. The advent of machines for agricultural operations has been one of the most outstanding breakthroughs in the global agriculture during the last decade [6]. These have spurred farming activities through stress reduction and increased output. Seed planters are agricultural implements that can be power driven or manually operated for the purpose of seed sowing in the field. A good planter should place seed in an environment for reliable and viable germination. The main benefits were to prevent excessive time wastage, ensure even spacing with uniformity, increase agricultural output, make crop cultivation less tedious and farming more attractive. Different planting machinery such as precision planters, grain drills, broadcasters and vegetable planters are available in the market. They give different types of precision and distribution pattern depending on the machine configuration and metering mechanism [6]. A precision planter help to save seed, reduce working hours, achieves more uniform spacing in the row and depth of planting. These help in producing crops uniform in height and strength a requisite factor for high yield.

To overcome reliance on human labour for sowing which results in delayed operation, low output and high production costs, indigenous planting equipment need to be developed and adopted. Many millstone achievements have been made in the area of planter development by researchers for various crops such as cowpea [7], okra [8], paddy [9], maize [10], cotton [11], groundnut [12], sorghum [13], multi-crop [14], soybean, corn and sorghum [15], cowpea, maize and soybean [16]. Although the mechanization of seeding process had generated significant interest in recent time, there is still need to revolutionize seed planting operations by making quality machines with high performance considering the technicality and economic capacity of the local farmers. Hence, this work focused on the design, construction and performance evaluation of an affordable self-propelled multi-crop two-row precision planter. The planter is for sowing maize, cowpea, and soybean, the major grain crops in the study area. The technology involved demonstrates the application of engineering techniques to reduce human labour taking into consideration its simplicity, maintainability, the relative ease with which it can be adjusted and maneuvered in the field to suit the technical know-how of an average Nigerian farmer.

2. MATERIALS AND METHODS

2.1. Design Considerations

The focus of this research was to produce a machine with a simple design, lightweight, durable and cost within the reach of the peasant farmers. In order to achieve this, several factors were taken into considerations. These include seed configurations, soil properties, availability and strength of construction materials, machine safety and ergonomics, ease of operation, power requirement, maintainability, reliability and efficiency of machine components. To maintain the quality of seeds, their viability should not be affected in any way during planting either through breakage or by any other means by the machine or any of its part, especially the seed metering device.

2.2. Design Computation of the Multi-crop Precision Planter

The machine was designed using an Autodesk tool. In order to obtain a reliable machine, the strength and stability of construction materials were of utmost importance so as to meet up with the required standard for efficient performance [17]. The design parameters considered were hopper capacity, power requirement, shaft and pulley diameters, belt tension and length. These were achieved using equations 1-9 [17-25].

The materials for construction were angle iron, mild steel, galvanized iron pipe, solid shaft, pulley, iron rods, bearing, bolts and nuts, and consumables. The machine design and construction pattern was to ease its usage and maintainability.

$$V = \pi r^2 h \tag{1}$$

$$V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 x A_2}\right) \tag{2}$$

$$\frac{N_2}{N_1} = \frac{D_1}{D_2} \tag{3}$$

$$\mathrm{V} = \frac{\pi d N}{60} \tag{4}$$

$$\mathrm{P} = \frac{2\pi N T}{60} \tag{5}$$

$$\mathrm{L} = 2\mathrm{c} + 1.571\,(D_2 - D_1) + \frac{(D_2 - D_1)^2}{4C} \tag{6}$$

$$d = \sqrt[3]{\frac{16T}{\pi\tau}} \tag{7}$$

$$\tau = 0.27\,\Upsilon_s \tag{8}$$

$$\mathrm{T}_{max} = \sigma \times A \tag{9}$$

where

A_1= area of the top of the hopper, m^2

A_2 = bottom area of the hopper, m^2

h = height of the hopper, m

D_1=diameter of the driver and D_2 = diameter of the follower, mm

N_1 = speed of the driver and N_2 = speed of the follower, rpm.

V- belt speed, m/s

P = power requirement, W

L= belt length, mm

C = distance between the centres of driving and driven pulleys, mm
d = diameter of the solid shaft, mm
T = Torque transmitted by the shaft, Nm
τ = Torsional shear stress, N/ m^2
Υ_s= yield stress, N/m^2
T_{max} = maximum permissible tension in the belt, N
σ = stress for the belt material, MPa
A =cross-sectional area, m^2

2.3. Description of the Precision Planter

The planter consists of two conjoined hoppers. The primary hopper is cylindrical made from mild steel of dimension 230 x 550 mm. It was connected through a shaft to the front wheel with bearing making rotation possible. It has a design capacity that can accommodate 16.5 kg of maize, 17 kg of cowpea and soybean. The primary hopper housed the seed metering mechanism. The secondary hopper is trapezoidal of dimension 300×200×100 mm made from mild steel which serves as a reservoir for the primary hopper. It has the capacity to hold 8 kg of maize, 8.3 kg of cowpea and soybean. The tapered end of the secondary hopper has a stopper plate that when open discharges it content to the opening on the primary hopper. The stopper on the primary hopper prevents its content from pouring out when it is rotating inside the bracket. Seeds were metered through the metering mechanism at the edge of the primary hopper. The machine has four wheels of dimensions 300 x 30 mm. The rear wheels serve as the driving or traction wheel connected to the prime mover using belt and pulley. The frame is of dimension 640 x 610 mm made from angle iron 4 mm thick. A hollow galvanized pipe was used to construct the planter handle taking into consideration human ergonomic factors. Mild steel of thickness 2 mm served as the engine seat that was slit for belt connection to the prime mover. An iron rod was constructed in the front and back of the primary hopper for attachment of the adjustable furrow openers and closers directly at the metering seed discharge line. They are made from mild steel designed to withstand soil resistance. The furrow opener is of shoe type because it can work well in trashy soils where the seed beds are not smoothly prepared. They are made from two flat pieces of steel welded together to form a cutting edge while the furrow closers are made of rectangular flat plate welded to a rod at the back. The exploded and isometric views of the machine are as shown in Figure 1 and 2.

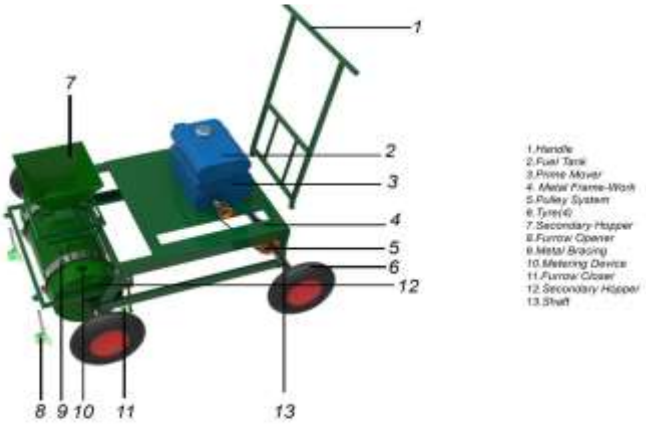

Figure 1 Exploded view of the planter

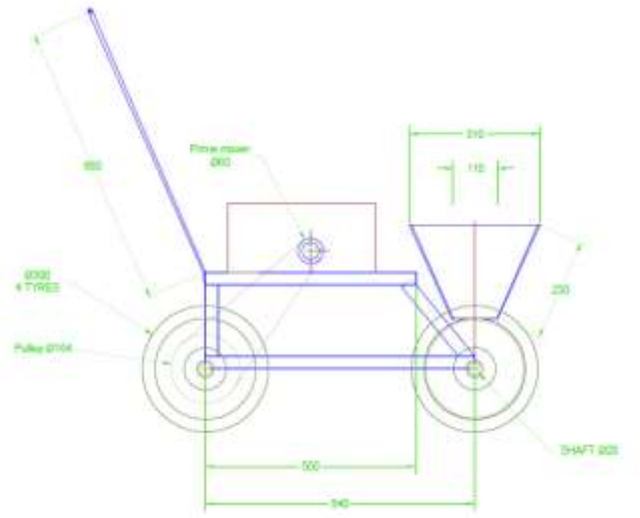

Figure 2 Isometric view of the precision planter

2.4. Description of the Metering Mechanism

The metering device is the major component of any planter as it plays a vital role in its performance. The major work carried out by a planter metering device is to distribute seeds uniformly at the desired application rates. They are used in planters to control seed spacing in a row. The technicality in getting the right setting for the metering mechanism for some of the imported planters is a major challenge. An apt indigenous technology will go a long way in overcoming the complexity involved in operating some of these imported farm machinery. The new design concepts of this planter tend to address this problem as it does not require any major setting.

The type of seed metering mechanism used for this design was basically precise holes of equal dimensions at an equal interval at the edge of the primary hopper. The physical geometry of the seeds to be handled was taken into consideration to arrive at the dimensions. The interval between the holes formed the seed-seed spacing while the inter-row is the distance between the holes at the edges of the primary hopper. The metering mechanisms consist of the discharge holes on the primary hopper and the hole on the bracket. The primary hopper was sectioned into four equal parts with each hole having a dimension of 20 x 15 mm made at the edge. A metallic bracket of width 70 mm having a single 30 mm opening at the bottom that aligned perfectly with the holes on the primary hopper was bolted to the frame. The clearance between the bracket and primary hopper was made 5 mm to permit only rotation without the discharge of any seed except when the hole on the primary drum get to the hole on the bracket. As the machine moves, the primary hopper connected to the front wheels rotate inside the bracket with seeds being discharged as the hole on primary hopper aligned with the hole on the bracket. Each side of the primary hopper has four holes at an equal interval on the drum as shown in Figure 3

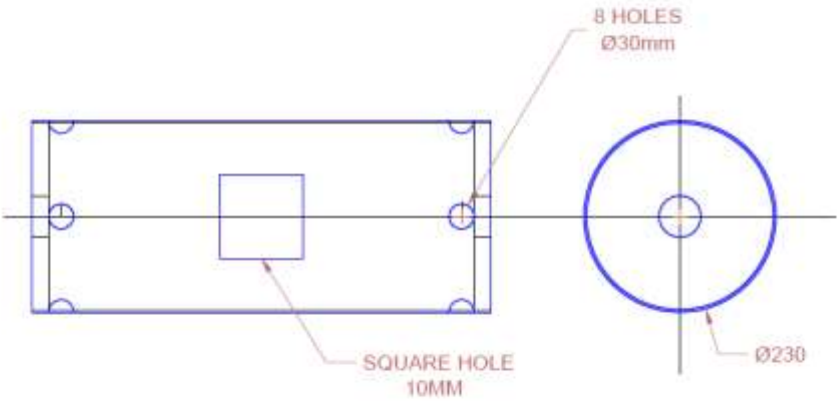

Figure 3 Metering mechanism on the primary hopper

2.5. Principle of Operation

Every component of the machine was designed to ensure ease of operation. The machine was powered by a petrol engine and power transmission was by belt and pulley arrangement to the driving shaft that engaged the wheels. Openings were created by the furrow openers set to a desired depth and the rotation of the primary hopper within the bracket drops the seed in the hole at desired intervals with the furrow closer covering the seeds dropped. Seeds are refilled from the secondary hopper by removing the stopper at the base of the hopper and the locker on the primary hopper when they are directly aligned.

2.6. Soil Analysis of the Sample Site

Soil samples were taken up to 21 cm depth for the determination of bulk density (BD) and moisture content (MC) using the gravimetric method. Cone penetrometer and soil shear vane were used to obtain soil cone index (CI) and shear strength (SS) up to a depth of 21 cm. The procedures described by [26] were used to obtain the textural soil classification of the experimental field.

2.7. Experimental Procedures for Evaluation

A laboratory test was conducted to investigate the seed discharge rate, uniformity of seed spacing and seed damage during operation at planting speed of 4.10, 6.14 and 8.25 km/hr. The laboratory study was carried out on the corridor of the Engineering Workshop Building of Landmark University, Omu Aran. A distance of 30 m was marked out on the corridor for determination of the operational speed of the machine. Seeds were loaded into the hoppers with the engine run at 100, 150 and 200 rpm. The time taken to cover the 30 m distance was recorded in three replications and used to calculate the speed in km/hr corresponding to 4.10, 6.14 and 8.25 km/ hr respectively.

2.8. Planter Performance Evaluation

Planting exercise was carried out to determine and observe the seeds distribution pattern along the rows. This was used in the calculation of some measurable parameters such as the number of seeds discharged or planted per hill, percentage seed damage, effective field capacity and field efficiency.

2.9. Determination of Percentage Seed Damage

The primary hopper was loaded with 4.1 kg of maize and 4.3 kg of cowpea and soybean seeds. A transparent nylon was laid on the floor on which the planter moved to ease evaluation and packing of the seeds after the laboratory experiment. The seeds discharged on each row were observed for any external damage and the procedure was repeated three times. Equation 10 was used to calculate the seed damage percentage.

$$Damage\,\% = \frac{N_d}{N_t}\,x\,100 \tag{10}$$

where

N_d = total number of damaged seeds

N_t = total number of seeds.

2.10. Determination of Field Capacity and Efficiency

The field tests were conducted for the determination of effective field capacity and field efficiency of the machine at planting speeds of 4.10, 6.14 and 8.25 km/hr. The experimental study was carried out at Landmark University Teaching and Research Farm on a 15 m x 30 m field having a sandy loam textural classification. To achieve a uniform field for planting, primary and secondary tillage operations were carried out using a plough and harrow. Pegs and ropes were used to mark the experimental field. The 30 m width of the field was further subdivided into 1 m each.

The investigation into the effective field capacity and field efficiency of the planter involved continuous observation and timing of each activity and time losses for turning at headland and adjustment. Two persons were involved in the evaluation, one operated the planter while the second observed and recorded the time taken for the exercise (time loss at field ends and time taken for the actual planting operation). The time taken was recorded using a digital stopwatch and the inter-row and seed width measured using a steel tape. The effective field capacities and field efficiencies were calculated using equations 11- 13 [8].

$$Effective\ field\ capacity\,\frac{(EFC)ha}{hr} = \frac{plot\ area\ \ (ha)}{Total\ time\ required\ to\ cover\ the\ plot\ (hr)} \tag{11}$$

$$Theoretical\ field\ capacity\ (TFC) = \frac{plant\ width\ x\ speed}{constant\ (10)} \tag{12}$$

$$Field\ efficiency = \frac{Effective\ field\ capacity}{Theoretical\ field\ capacity}\,x\,100\% \tag{13}$$

or

$$Field\ efficiency = \frac{time\ for\ actual\ operation}{total\ time\ taken}\,x\,100 \tag{13}$$

3. RESULTS AND DISCUSSION

3.1. Soil Characteristics of the Experimental Site

The analysis of the soil sample of the experimental site shows a sandy loam classification with 6.04, 9.00 and 84.96% of clay, silt, and sand respectively as presented in Table 1. The bulk density, moisture content, cone index and soil shear strength ranged from 1.01-1.58 g/m^3, 5.73-11.76%, 95-120 kPa and 105-155 kPa respectively. Values obtained show favourable conditions for smooth performance of the planter in the field based on the machine design parameters.

Table 1 Soil characteristics observed for the experimental site

Clay (%)	6.04
Silt (%)	9.00
Sand (%)	84.96
USDA textural class	Sandy Loam
BD (g/m3)	1.01-1.58
MC (%)	5.73-11.76
CI (kPa)	95-120
SS (kPa)	105-155

3.2. Laboratory and Field Performance Evaluation Results

The results obtained from the laboratory testing of the planter for maize, cowpea, and soybean is as presented in Table 2. It was observed that the quantity of seed discharged was affected by the speed of operation. At a reduced speed, the number of seeds discharged was high. This may be due to the long residence time of the seeds at the discharge hole as the primary hopper rotates thereby permitting many seeds to drop. The desired number of seeds discharged was obtained at 8.25 km/hr speed of operation. The planter effectively discharged between 2-3 seeds per hole for maize and cowpea while 3-4 seeds per hole were obtained for soybean. This may be due to the high sphericity of soybean; hence it tends to roll and discharge easily than maize and cowpea [4]. Therefore, for best performance of the planter, a speed of 8.25 km/hr was recommended when using it on a sandy loam soil. The planter performance was satisfactory because the recommended number of seeds were discharged from the metering device which was similar to observation made by [16] in a developed manual planter.

Table 2 Mean and standard deviation of seed discharge at various engine speed (g)

S/N	Speed(km/hr)	Maize	Cowpea	Soybean
1	4.10	7.50±0.30	5.60±0.10	5.77±0.15
2	6.14	6.57 ±0.25	4.17± 0.15	5.37 ±0.15
3	8.25	5.73±0.15	3.57±0.21	4.47±0.15

Also, minimum mean percentage seed damage values were observed at 8.25 km/hr with maize having 3.53, cowpea 3.17 and 2.53% for soybean when compared to other levels of speed investigated as shown in Table 3. The value obtained in soybean may be as a result of the physical configuration of the seed. Observations obtained was similar to performance output of other researchers investigations [7, 8, 9, 27].

Table 3 Mean and standard deviation for percentage seed damage at the various engine speeds

S/N	Speed (km/hr)	Maize	Cowpea	Soybean
1	4.10	5.87±0.45	5.80±0.50	4.47±0.35
2	6.14	4.80±0.10	4.20± 0.70	3.40±0.10
3	8.25	3.53±0.31	3.17± 0.65	2.53± 0.31

Field efficiency was observed to be 81.2% of the mean values of the field efficiencies obtained. This shows a good and satisfactory performance as is within the range of values obtained for planting operation from the work of [8]. Also, an effective field capacity of 0.1 ha/hr was obtained from the field evaluation. The machine performance output is satisfactory when compared with similar results reported in some literatures for a motorized seed planter [7, 10]. Field efficiency of 76.3% and field capacity of 0.03 ha/hr was obtained in a manual planter developed by [16].

4. CONCLUSION

A motorized self-propelled multi-crop precision planter was developed having a new metering mechanism design concept. It was evaluated both in the laboratory and field using maize, cowpea, and soybean to obtain measurable parameters such as field efficiency, field capacity, time of operations and the percentage of seed damage. This is to observe and establish the functionality and performance of the planter. Results obtained show that the speed of operation has an effect on the performance indices investigated. At lower engine speed, a high number of seeds were discharged and percentage damage was also high. Best field performance of the planter was obtained at 8.25 km/hr working speed with a field efficiency of 81.2%, field capacity of 0.1 ha/hr and minimal seed damage (2.53–3.53 kg). The planter was able to correct the problems of metering mechanism setting associated with conventional planters and manual methods of seed planting such as poor seed placement, poor spacing efficiency, and serious farm drudgery.

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