

DEVELOPMENT AND PERFORMANCE EVALUATION OF A THREE-ROW MULTI-GRAIN PLANTER

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ABSTRACT

Mechanization has revolutionized farming practices by facilitating timely operations, reducing losses, and cutting operational costs, ultimately enhancing agricultural productivity. The rising demand for functional and affordable planters, coupled with the inability of Nigerian farmers to afford imported planters, highlights the need to develop locally produced planters to address the primary limitations and obstacles faced with existing planting equipment and systems, such as low efficiency, labour intensity, safety concerns, and soil compaction issues. The study focused on the design and fabrication of a three-row push-type multipurpose planter using locally available materials. The aim was to address the specific needs and challenges faced by rural and medium-scale farmers. The performance of the developed planter was evaluated through both laboratory and field tests. The laboratory assessment aimed to measure the rate of seed discharge and assess seed damage during operation, while the field test sought to gauge field efficiency and throughput capacity of the developed machine. Results from both tests indicated promising outcomes. The three-row planter discharged seeds; maize weighing 4.67 to 4.71 g, soybean ranging from 10.65 to 10.89 g, and cowpea weighing from 4.07 to 4.69 g while effectively metering out two to three seeds per discharge at an average planting depth of 3.88 cm. Minimal seed damage was recorded, with percentages of 1.07% for maize, 0.92% for soybeans, and 0.71% for sorghum. Field tests revealed a commendable field efficiency of 73.5% and an average field capacity of 0.188 ha/hr., Hence, the designed planter is simple to operate, portable, easy to maintain., and it has the potential to alleviate the challenges faced by farmers in rural areas.

Keywords: Grains, Multi-crop planter, Metering device, Seed cover, Traction wheel.

INTRODUCTION

Planting is an essential process of embedding seeds in the soil to facilitate optimal germination, which is an important cultural practice associated with crop production to achieve a plant stand of desired density, characterized by quick and uniform emergence (Alhassan and Adewumi, 2018). Successful seed planting involves the correct seed quantity per unit area, appropriate seed depth in the soil, and accurate spacing between rows and plants. This operation is crucial for efficient harvesting in mechanized farming systems (Alhassan and Adewumi, 2018; Adisa and Braide, 2012; Adekanye and Akande, 2015).

The seed-to-seed spacing is a major dependent on the crop type and the specific agro-climatic conditions necessary for optimal yield. A uniform seed distribution

within the soil enhances germination and emergence, ultimately increasing yield by minimizing competition among plants for essential resources such as light, water, and nutrients. The various factors influence seed distribution in the soil, including the seed metering system (Soyoye, 2020), seed delivery tube, furrow opener design, physical properties of the seed, and soil conditions. Manual seed sowing is a labor-intensive process, prompting the need for mechanization to enhance efficiency and better output. Timeliness in agricultural operations is paramount, and the use of appropriate machines becomes essential for achieving better productivity (Bisen *et al.*, 2021). In Nigeria, manual seed planting is prevalent, characterized by its slow, tedious, time-consuming, and expensive nature, often resulting in poor seed placement, and spacing

efficiency, leading to low yield and productivity (Alhassan *et al.*, 2023).

The introduction of agricultural machines over the last decade has significantly transformed global agriculture. Seed planters, whether power-driven or manually operated, play a crucial role in this transformation by facilitating efficient seed sowing in the field. A well-designed planter ensures that seeds are placed in an environment conducive for viable germination (Abdulkadir *et al.*, 2020). The benefits of using such machinery include preventing excessive time wastage, ensuring even spacing with uniformity, increasing agricultural output, reducing the tedium of crop cultivation, and making farming more attractive. The various types of planting machinery, such as precision planters, grain drills, broadcasters, and vegetable planters, are available in the market (Alhassan and Adewumi, 2018). These machines offer different levels of precision and distribution patterns based on their configurations and metering mechanisms. Precision planters, for instance, contribute to seed savings, reduced working hours, uniform spacing in the row, and consistent planting depth, ultimately leading to crops that are uniform in height and spacing, a requisite factor for achieving high yields.

In order to address the drawbacks associated with dependence on human labour for sowing, leading to delays in operations, reduced output, and increased production costs, it is imperative to design and embrace indigenous planting equipment. Considerable strides have been accomplished in the field of planter development by researchers, targeting a variety of crops (Abubakar *et al.*, 2020; Adekanye and Akande, 2015; Adisa and Braide 2012; Alhassan and Adewumi, 2018; Soyoye, 2020). More so, the mechanization of the seeding process has garnered notable attention in recent times, there remains a pressing need to innovate seed planting operations by developing high-performance machines that align with the technical and economic capabilities of local farmers. Specifically tailored for planting maize,

cowpea, and soybean, essential grain crops in the region under investigation, this innovation utilizes engineering techniques to alleviate human labour. Emphasizing simplicity, ease of maintenance, and maneuverability, the technology is designed to cater for the technical competency of the typical Nigerian farmer, offering adjustable features for field operations.

This versatile grain planter was specifically designed to address the primary limitations and obstacles faced with existing planting equipment and systems, such as low efficiency, labour intensity, high costs, safety concerns, and soil compaction issues. The precision of the planting process heavily relies on its metering device, which serves as a crucial component of any planter and is specially designed with castellations. Traditionally, a ground wheel has been employed to power the metering device, yet it encounters significant resistance and is prone to slipping. To counter this, the seeding mechanism has been affixed onto a metal frame supported by the chassis. This frame, crafted from a lightweight hollow square pipe, maintains the planter's structural integrity while simultaneously reducing its overall weight, thus mitigating soil compaction concerns. To further optimize the planter's performance, chisel openers have been integrated, preceded by coulter discs. These discs serve to cut through straw ahead of the furrow openers, facilitating smoother penetration and operation. Therefore, the study is centered on the design, construction, and performance assessment of a cost-effective, push-type, multi-crop three-row planter.

METHODOLOGY

Conception of the planter

The designed machine was characterized with simple design, lightweight structure, robust durability, and affordability, with a specific focus on making it accessible for peasant farmers. Achieving these objectives involved a meticulous consideration of various factors throughout the research

process. These factors comprised of seed configurations, soil characteristics, the accessibility and durability of construction materials, machinery safety, ergonomics, operational simplicity, power demands, upkeep requirements, and the dependability and effectiveness of machine elements. A critical element in the machine's design was the preservation of seed quality. It was important that the seeds' viability remained unharmed during the planting process, preventing potential damage or breakage caused by the machine or its components, especially the seed metering device. This emphasis on seed quality aimed to ensure optimal performance and successful crop cultivation for peasant farmers, maintaining the integrity of the planting process without compromise.

Machine Description

The planter was designed to consist of the following parts as shown in Figures 1 to 3. The components include frame, handle, traction wheels, seed hopper, furrow openers, metering device delivery tubes and covering devices as described below:

Frame is foundational element of the machine that serves as the base to which all other components are affixed. Constructed from mild steel, the frame comprises a 95 x 25 cm rectangle pipe. The handle is crafted from a hollow pipe with an internal diameter of 9 mm, measuring 90 cm in length and 40 cm in width. A bushing with a 21 mm internal diameter was welded horizontally to the handle to facilitate its attachment. This design enables operators of varying heights to comfortably utilize the handle. Attached to the transport wheels is a horizontal bevel gear system that engages the three-metering mechanism as the wheels rotate. The metering mechanisms are equipped with castellations, enabling each point to pick up two seeds simultaneously from the seed box. The seed hopper, a critical part of the design, is fashioned from 1.5 mm thick mild steel sheet metal. Positioned on top of the frame, it assumes a trapezoidal shape with a 45° slant toward the bottom and a height of 26 cm. The

traction wheels, fashioned from mild steel and boasting a 35 cm diameter, feature six mild steel bars welded onto the pipe, strategically positioned at the wheel's center. Two traction wheels were securely fixed on either side of the frame. The drive wheels were outfitted with 10 mm-long steel pieces, cut from iron rods with a diameter of 10 mm that offer essential resistance against soil rolling during the machine's forward motion. The furrow opener adopts a disc coulter design manufactured from mild steel, featuring a diameter of 4 cm. The seed delivery tube, situated below the metering device, receives the seeds released, conveying, and depositing them into the furrow opened while the furrow covering device covers the deposited seeds.

Design of Shaft Diameter

The maximum shear theory for a solid shaft experiencing minimal or no axial loading as reported by Abdulkadir *et al.* (2020) and expressed in Equation (1).

$$d^3 = \frac{16}{\pi S_s} [(K_b M_b)^2 + (K_t M_t)^2]^{\frac{1}{2}} \quad (1)$$

where,

d = diameter of the shaft, mm,

M_t = maximum torsional moment on shaft, Nm,

M_b = maximum bending moment on shaft, Nm

K_t, K_b = fatigue and shock factor for torsion and bending moments.

S_s = allowable combined shear stress for bending and torsion for steel shaft,

and π = constant = 3.14.

Determination of planter maximum draft

The maximum draft experienced by the planter refers to the horizontal force exerted in the direction parallel to its motion, necessary to overcome the resistance posed by the soil. The maximum draft was determined using relationship illustrated in Equation (2) (Adekanye and Akande, 2015).

$$D_{FM} = R_s \times A_{FO} \quad (2)$$

where,

D_{FM} = Maximum draft (N),

R_s = Soil resistance (Kg/cm²),

A_{FO} = Recommended depth of cut × Thickness of furrow opener (cm²).

Determination of seed rate requirement

The seed rate for the planter was determined using Equation (3) and (4). (Adekanye and Akande, 2015).

$$SR = \frac{1000}{W \times S_C} \times \frac{1}{1-S} \times SW_{IR} \quad (3)$$

$$W_{IR} = Zab \times \frac{q}{1000} \quad (4)$$

where;

W = Machine width (0.70 m as the inter row spacing, commonly used in the study area).

S_C = Planter wheel circumference,

S = Slip expressed in fraction,

W_{IR} = Weight of seeds drop for one revolution of the wheel,

Z = Number of grooves on the metering device (maximum value of 3, from design assumption),

a = grains number per stand (2), b = number of planting rows (3), and q = weight grains

Determination of the force required for traction (Power Requirement)

The force required to push the planter was derived from the relationship in Equations (5) and (6).

$$F_P = \frac{R_s \cos \phi + W_P}{\cos \theta} \quad (5)$$

$$R_s = \frac{F_R \tan \phi + W_P}{(S \sin \phi - \cos \theta \tan \theta)} \quad (6)$$

where,

F_P = Push force of the planter,

F_R = Horizontal resistance force of the soil, kg/cm²

R_s = Soil frictional resistance force of the soil.

ϕ = Angle of friction,

θ = Angle between horizontal plane and planter handle,

W_P = Planter weight, kg.

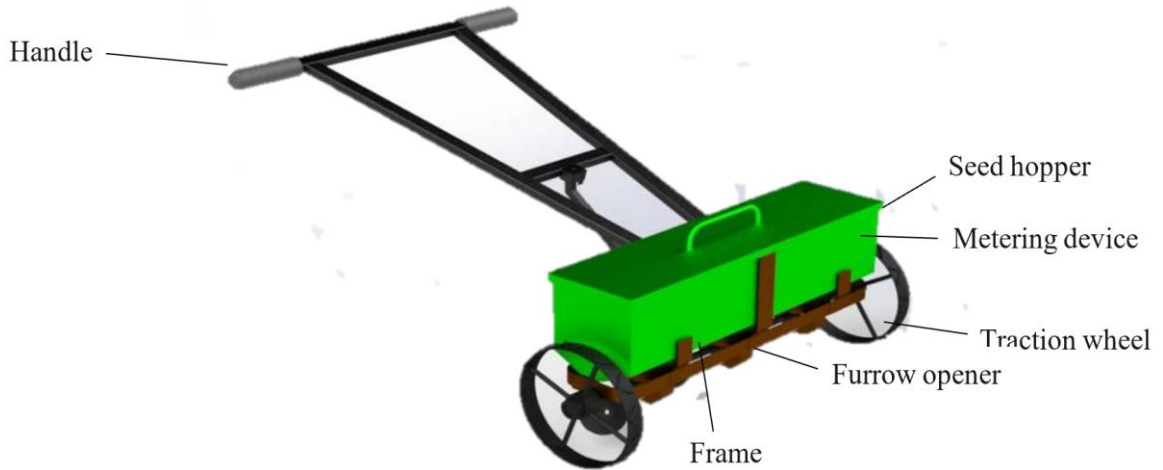


Fig. 1: Exploded view of the designed model of Three Row Multi-Grains Planter

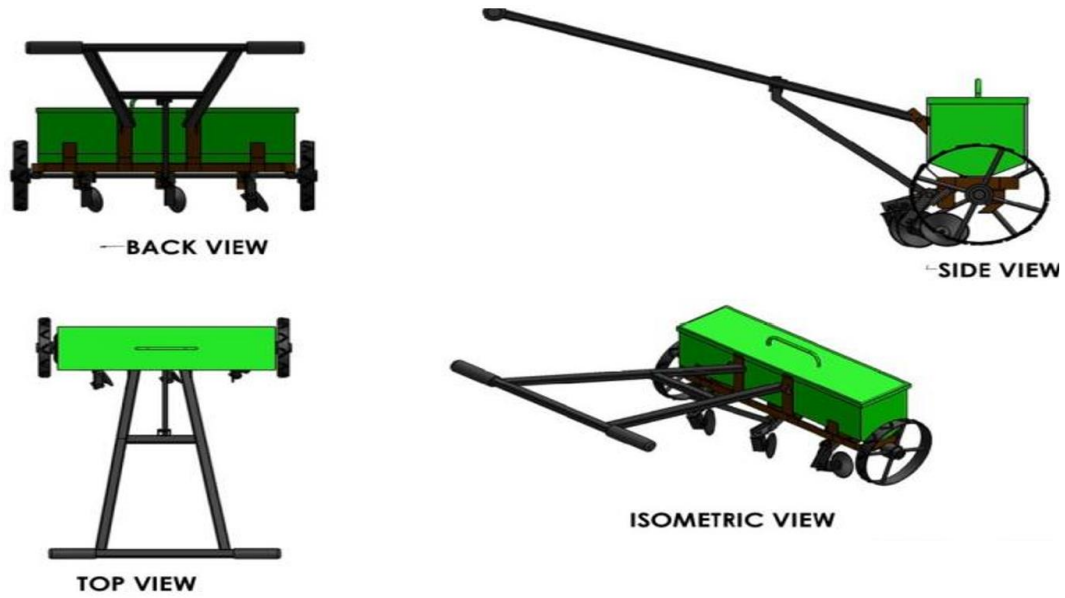


Fig. 2: Orthographic View of the Designed Three Row Multi-Grains Planter



Fig. 3: Pictorial View of Three Row Multi-Grains Planter

Machine Mode of Operation

The machine operates on a simple principle, it required only one person for its operation. The planting process involves pushing the device along a prepared seedbed. Attached to the drive/transport wheels is a horizontal bevel gear system, which activates the metering mechanism as the wheels turn in motion. The three metering mechanisms are designed with castellations, allowing each castellated point to pick up two seeds simultaneously from the seed box. These seeds are consistently introduced into the discharge tube, which deposits them into the opened soil. Subsequently, the furrow covering device covers the deposited seeds.

Seed Delivery Rate (R_S)

Seed delivery rate was determined using the relationship stated in Equation (7) as reported by Alhassan *et al.* (2023).

$$R_S = \frac{Q_p}{A} \quad (7)$$

where,

R_S = Seed delivery rate (kg/ha),

A = Planted field area (ha),

Q_p = Quantity of planted seeds (kg).

Seed Damage (D_S)

Seed damage was also determined using the relationship stated in Equation (8) as reported by Alhassan *et al.* (2023).

$$D_S = \frac{Q_d}{Q_p} \quad (8)$$

where,

D_S = Damage seeds (%),

Q_d = Quantity of damage seeds (kg),

Q_p = Quantity of planted seeds per unit area (kg)

Laboratory Tests

Laboratory analysis was conducted to identify and inspect potential malfunctions and defects in the design, as recommended by Adekanye and Akande (2015). The identification of any defects would prompt modifications and enhancements to the machine design. Throughout the testing process, the quantity of seeds discharged per outlet and the number of damaged seeds were

observed and documented. The hopper was first loaded with 5 kg of maize, followed by soybean, and cowpea seeds in each case. The planter was then suspended, and the wheel was rotated for a specified duration. The purpose of wheel rotation was to power/rotate the metering device. In each investigative run, the drive wheels were rotated 50 times at a low speed. A stopwatch was used to record the time required to complete the revolutions.

The discharged seeds were meticulously weighed on a precision weighing balance, and this procedure was repeated five times for accuracy and reliability in the results. The findings from this laboratory testing process served as a crucial step in identifying and rectifying any issues in the machine design, ensuring optimal performance and functionality. The effect of the hopper capacities on the seed discharge and application rates was noted and tabulated. At each instance, Equations (9) and (10) were used to calculate the discharge and application rates respectively.

$$\text{Discharge rate} = \frac{\text{Quantity of seed dropped}}{\text{Time taken}} \quad (9)$$

$$\text{Application rate} = \frac{\text{Quantity of seed dropped}}{\text{Area of the land covered}} \quad (10)$$

Field Evaluation

The seeds were directly planted in a designated plot measuring 25 m x 25 m, totaling 625 m², which was demarcated in the field. This plot underwent ploughing and harrowing to establish a well-prepared seedbed. The planting process aimed to assess the seed distribution pattern, specifically examining the dispersion of seeds along rows. The assessment encompassed several key factors: number of seeds dispensed and planted per plant stand, identifying any gaps along the rows, monitoring seed emergence, determining the effective field capacity and efficiency. To evaluate field efficiency and effective capacity, continuous observation and timing of each planting activity were performed.

Two individuals were involved in assessing field efficiency: one operated the planter while the other recorded the time for various tasks and observations, including time losses such as turning at field ends, stump removal, and adjustments like changing the metering device. Equations (11) and (12) were used to calculate the planter's field efficiency and throughput capacity. The average depth of seed placement was determined by running the planter at a 45° angle to the soil surface across the area under investigation. The furrow opener was adjusted moderately to keep furrows opening without covering the holes. The time taken to traverse the field's length was recorded to calculate the average depth of seed planting. Operating this planter in the field proved to be relatively straightforward, primarily due to the well-prepared seedbed. The furrow opening device was easily adaptable to the varying topography of the land as required.

$$\text{Field Efficiency} = \frac{\text{Actual time spent on planting operation}}{\text{Total Time taken}} \times 100 \quad (11)$$

$$\text{Field Capacity} = \frac{\text{Area Covered (ha)}}{\text{Total Time taken (hr.)}} \quad (12)$$

Seed Emergence Ratio.

The seed emergence ratio, which represents the proportion of seeds that successfully sprout from the soil compared to the total number of seeds initially planted. Emergence assessments were conducted three weeks following the planting of seeds, as determined by the equation (13) as reported Adekanye and Akande (2015).

$$G_p = \frac{P}{S} \quad (13)$$

where;

G_p = the emergence percent,

P = Average plant seeds per 10m along the sowing row,

S = Average number of seeds delivered per 10m along the planting row.

RESULTS AND DISCUSSION

Results of laboratory and field Tests

Tables 1, 2, and 3 exhibit the outcomes derived from calibrating the planter for cowpea, maize, and soybean. From the data presented, the average weight of seed discharge for maize, cowpea, and soybean were 4.69 g, 4.40 g, and 10.76 g, respectively. The cumulative average weight of discharged seeds during calibration amounted to 19.83 g, with a mean discharge of 6.61 g. Notably, this falls within the recommended range of ± 7 for optimal inter-furrow variation as stated by Bamgboye and Mofolasayo (2006). On average, the planter effectively dispensed 2 seeds per hole, aligning with its intended functionality as the anticipated number of seeds were discharged from the metering device. Consequently, the planter's design performance can be deemed satisfactory.

Field efficiency and field capacity

According to Table 4, the field efficiency recorded an impressive 73.5% based on the average values obtained from field efficiency trials. This performance falls comfortably within the range of values reported for planting operations by previous researchers (Singh *et al.*, 2020; Oduma *et al.*, 2014; Bamgboye and Mofolasayo, 2006), indicating satisfactory functionality. Additionally, the planter exhibited an effective field capacity of 0.188 ha/hr, a value consistent with findings by Bamgboye and Mofolasayo (2006). Notably, this capacity surpassed that of manually operated seeding attachments, such as the animal-drawn cultivator developed by Kumar *et al.* (1996) and the template row planter devised by Adisa and Braide (2012), which recorded capacities of 0.28 ha/hr. This positive outcome can be attributed to the planter's maneuverability, which streamlines the process and saves time during movement and turning. Ani *et al.* (2016) developed and evaluated a vertical plate maize seed planter tailored for gardens and smallholder farmers, achieving an efficiency rate of 73.4% and operating three times faster than manual

planting with hoes and cutlasses. Similarly, Olajide and Manuwa (2014) reported an effective field capacity of 0.36 ha/hr. with an efficiency of 71%. Table 4 also shows that, maize exhibits a higher emergence percentage (85%) compared to other crops, whereas cowpea demonstrates the lowest emergence percentage (75%). It's worth noting that the research was conducted prior to the cowpea planting season, which could explain the lower emergence rate observed for cowpea in the study. Furthermore, Tables

1, 2, and 3 present the average percentage of seed damage for maize, cowpea, and soybean, amounting to 1.07%, 1.45%, and 0.9%, respectively. Notably, average values for percentage seed damage in this study were lower compared to the 3.15% damage reported by Bamgboye and Mofolasayo (2006). Seed damage may stem from minimal clearance between the metering devices (flute) and their housing, as well as the low speed at which the planter wheels rotated during laboratory test.

Table 1: Percentage seed damage during operation (Maize)

Furrow	S/N	Time for 20 rev (min)	speed (rpm)	No of seeds discharged	No of seeds damaged	Percentage damage (%)	Weight of seed discharge
A	1	1.95	23.6	80	0	0	5.01
	2	2.80	27.9	79	2	2.5	4.56
	3	1.78	30.9	73	1	1.4	4.76
	4	2.32	41.2	59	0	0	4.20
	5	2.45	29.5	68	2	2.9	4.96
Average		2.26	30.6	71.8	1	1.36	4.69
B	1	2.31	34.7	75	0	0	5.12
	2	2.72	30.9	70	0	0	4.89
	3	1.96	29.7	82	1	1.22	4.90
	4	1.67	27.9	79	0	0	4.79
	5	2.09	31.9	81	2	2.47	3.84
Average		2.15	31.02	77.4	0.6	0.74	4.71
C	1	1.79	35.8	73	1	1.37	3.68
	2	2.03	30.8	70	0	0	4.67
	3	1.98	42.2	69	1	1.45	5.20
	4	2.88	38.5	73	2	2.74	4.92
	5	1.80	29.8	79	0	0	4.87
Average		2.1	35.42	72.8	0.8	1.11	4.67
Grand Average		2.17	32.25	74	0.8	1.07	4.66

Table 2: Percentage seed damage during operation (Cowpea)

Furrow	S/N	Time for 20 rev (min)	speed (rpm)	No of seeds discharged	No of seeds damaged	Percentage damage (%)	Weight of seed discharge
A	1	2.65	27.6	81	0	0	5.80
	2	2.93	29.3	78	2	2.56	5.10
	3	3.03	36.9	74	1	1.35	4.87
	4	2.32	35.2	62	0	0	4.51
	5	2.65	39.6	70	1	1.43	3.83
Average		2.72	33.72	73	0.8	1.07	4.82
B	1	2.51	34.6	73	1	1.37	4.0
	2	2.12	32.5	72	2	2.78	4.92
	3	1.86	29.8	80	1	1.25	5.48
	4	2.97	27.0	82	0	0	5.83
	5	2.69	30.2	79	2	2.53	4.78
Average		2.43	30.82	77.2	1.2	1.59	5.0
C	1	1.63	33.5	70	2	2.86	4.98
	2	2.73	32.8	68	0	0	4.07
	3	1.97	40.2	67	1	1.49	5.62
	4	2.86	36.5	71	2	2.82	4.65
	5	2.89	39.8	77	1	1.3	3.99
Average		2.42	36.56	70.8	1.2	1.69	4.66
Grand Average		2.52	33.7	73.6	1.07	1.45	4.5

Table 3: Percentage seed damage during operation (Soybeans)

Furrow	S/N	Time for 20 rev (min)	speed (rpm)	No of seeds discharged	No of seeds damaged	Percentage damage (%)	Weight of seed discharge
A	1	2.35	22.6	81	0	0	10.40
	2	2.50	27.9	72	2	2.78	10.52
	3	1.98	34.9	78	1	1.28	9.98
	4	2.82	31.2	69	0	0	10.51
	5	2.85	29.3	67	1	1.45	11.83
Average		3.01	29.18	73.4	0.8	1.10	10.65
B	1	2.81	33.7	72	1	1.39	11.37
	2	2.92	32.9	75	0	0	10.92
	3	2.86	27.7	80	1	1.25	10.48
	4	1.87	22.9	79	0	0	10.83
	5	1.99	30.9	85	1	1.17	10.78
Average		2.49	29.62	78.2	0.4	0.76	10.88
C	1	1.79	32.8	70	1	1.43	11.76
	2	2.03	30.8	73	0	0	10.87
	3	1.98	40.2	69	1	1.45	10.76
	4	2.88	39.5	79	1	1.27	10.65
	5	1.80	30.8	78	0	0	10.39
Average		2.09	34.82	73.4	0.4	0.83	10.89
Grand Average		2.53	31.21	75	0.53	0.9	10.81

Table 4: Field efficiency and effective field capacity of the planter

Field activities	Furrow A Time / ha (min)	Furrow B Time / ha (min)	Furrow C Time / ha (min)
Filling of seed box	15.7	15.9	15.5
Turning at field	18.6	18.8	18.3
Removal of clogs	19.8	19.6	19.5
Actual planting	155	150	145
Average planting depth (cm)	3.98	3.85	3.80
Seed emergence ratio			
Maize (85%)	230	220	235
Cowpea (75%)	185	185	205
Soybean (78%)	190	198	205
Total time	209.1	204.3	198.3
Field efficiency (%)	74.1	73.4	73.1
Field capacity(ha/h)	0.190	0.188	0.187

CONCLUSION

A push-type three-row multi-crop planter was designed and fabricated, incorporating an innovative metering mechanism. Extensive evaluations have been conducted, both in field settings and within laboratory conditions, utilizing maize, cowpea, and soybeans. Key metrics such as field efficiency, throughput capacity, operational time, and seed damage percentage were measured. These assessments were aimed at understanding and confirming the functionality and effectiveness of the planter. The planter successfully metered 2 seeds per hole, minimizing seed wastage. Operating on a prepared seed bed, the multi-crop planter demonstrated an average field capacity of 0.188 hectares per hour, coupled with an average field efficiency of 76.3%, making it suitable for small-scale farming. The overall production cost was ₦120,500 only. Maintaining the machine is straightforward and does not require much technical expertise.

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