*Advances in Modern Agriculture (2023) Volume 4 Issue 2*
doi: 10.54517/ama.v4i2.2239

Asia Pacific Academy of Science Pte. Ltd.

ORIGINAL RESEARCH ARTICLE

# Urban agriculture empowerment: Donkey-driven maize planter for sustainable food production in Sub-Saharan African cities

**O.M. Seretse[1,*], Abhishek Agarwal[2], Ulaula Mmiletsi[1], Mbizo Mpho[1]**

[1] *Department of Mechanical Engineering, University of Botswana, Gaborone 4775, Botswana*

[2] *Department of Mechanical & Manufacturing Engineering Technology, Vermont State University, Randolph, VT 05061, USA*

*** Corresponding author:** O.M. Seretse, seretseom@ub.ac.bw

## ABSTRACT

The lack of affordable and lightweight mechanized maize planters suitable for small-scale farms in Botswana, where donkeys serve as the primary source of draught power, poses a significant challenge. This study addresses this issue by designing a cost-effective model of a two-row donkey-drawn maize planter. A comprehensive analysis of various existing planter technologies was conducted, and their principles were carefully adapted to develop an optimal two-row planter suitable for donkey traction. The selection of appropriate materials for each component, accompanied by the use of SolidWorks software for detailed drawings and fabrication, resulted in a user-friendly planter design. The mass estimation of the assembled planter was calculated to be 48.93 kg, making it light enough to be drawn by three donkeys. Notably, the estimated cost of the unit planter assembly is approximately 200 USD. Despite these advancements, it is important to acknowledge certain limitations. This study introduces an innovative solution to address the need for affordable, lightweight, and donkey-drawn maize planters in Sub-Saharan Africa. By leveraging existing technologies and employing appropriate materials, the proposed design offers a practical and cost-effective option for small-scale farmers. Further research is necessary to assess the planter's performance under varying soil conditions, evaluate its long-term durability, and optimize its planting efficiency. Additionally, consideration should be given to implementing additional features such as seed depth control mechanisms and adjustable row spacing to enhance the versatility of the planter.

***Keywords:*** urban agriculture; small-scale farming; affordable mechanized planters; sustainable food production; lightweight design; cost-effective model; donkey-drawn planter

## 1. Introduction

Urban development plays a crucial role in shaping sustainable and resilient cities, with a focus on improving the quality of life for urban residents. One significant aspect of urban development is ensuring efficient and productive agricultural practices within urban areas. Planting, the process of seed placement in the soil, is a fundamental activity in agriculture and contributes to the availability of fresh produce in urban settings.

Planting is an essential practice in agriculture, involving the strategic placement of seeds in the soil to ensure optimal germination and crop growth. Throughout history, various methods have been employed for

**ARTICLE INFO**
Received: 7 July 2023 | Accepted: 15 December 2023 | Available online: 22 December 2023

**CITATION**
Seretse OM, Agarwal A, Mmiletsi U, Mpho M. Urban agriculture empowerment: Donkey-driven maize planter for sustainable food production in Sub-Saharan African cities. *Advances in Modern Agriculture* 2023; 4(2): 2239. doi: 10.54517/ama.v4i2.2239

planting, starting from manual techniques using hands, stones, and hand tools, to more mechanized approaches involving the use of tractors or animals, such as oxen or donkeys, to tow farm implements[1]. Notably, the utilization of strong working animals has been deeply ingrained in the traditional farming practices of small-scale farmers.

A planter is a crucial device that facilitates the efficient sowing of seeds in desired positions, offering farmers significant time and cost savings[2]. The primary objective of a planter during the sowing operation is to accurately deposit seeds in rows at the desired depth and seed-to-seed spacing, cover them with soil, and ensure proper compaction over the seeds[3,4]. Although there is a growing preference for tractor-farm technology in recent years, animal-drawn equipment still holds substantial relevance and continues to be widely utilized by small-scale farmers[5]. During the design of planting equipment, it is imperative to consider various seed properties to determine the optimal layout factors[1]. Factors such as seed size, shape, and hardening characteristics inform the appropriate cup size on the seed plate, while seed weight aids in selecting suitable materials for the planter frame. Additionally, mass density and moisture content help establish the correlation between seed properties and the material used for the planter container, especially under high-temperature conditions[6]. It is well-established that improper planting techniques can result in non-uniform seed distribution, excessive seed and fertilizer consumption, nutrient and sunlight competition among seedlings, and challenges in subsequent management practices, particularly without the use of efficient tools[7]. In Botswana, a developing country, the majority of small-scale farmers in rural areas rely on donkeys as their primary source of draught power due to the high costs associated with tractors[8]. In the past, sowing small grain crops like wheat or oats involved manually scattering seeds across the field and covering them with harrowing. This process was labor-intensive and inefficient, leading to the wastage of seeds due to bird consumption or inadequate contact with moisture and soil. However, in 1701, Jethro Tull revolutionized the planting process by inventing a model seed driller capable of metered seed placement at the correct depth, subsequently enhancing crop growth[9]. Furthermore, the introduction of straight-line ‘seed drilling’ by Tull’s invention enabled the use of horse-drawn cultivators to remove weeds from between the rows[10]. Tull’s seed drill, enhanced with gears in 1782, significantly improved crop yield ratios, eventually replacing the manual broadcasting of seeds[9]. **Figure 1** depicts Jethro Tull’s original seed drill design.

**Figure 1.** Jethro Tull seed drill[11].

In the realm of agricultural innovation, the late 18th century witnessed a pivotal advancement in ‘seed drilling’ technology pioneered by Jethro Tull. Tull’s groundbreaking seed drill, initially developed in 1701, revolutionized the planting process by introducing a metered stream of seeds into the soil at the appropriate depth, resulting in enhanced crop growth and yield[12]. Building upon Tull’s original design, subsequent improvements were made to the seed drill in 1782, incorporating gears into the distribution mechanism for more efficient seed dispersal[12].

As the 19th century unfolded, a wave of agricultural innovation swept across the landscape, giving rise to a myriad of sophisticated farming implements. Notably, this era witnessed the introduction of technologically advanced seeders manufactured by renowned pioneers such as Billings, Pratt, Cole, Emery, and Harrington[12]. These visionary inventors pushed the boundaries of agricultural machinery, elevating the technical prowess of the farming industry to unprecedented heights. Among the remarkable innovations of this period was Billing's single-row horse-drawn corn planter, depicted in **Figure 2**, which further optimized the precision and efficiency of seed planting processes.

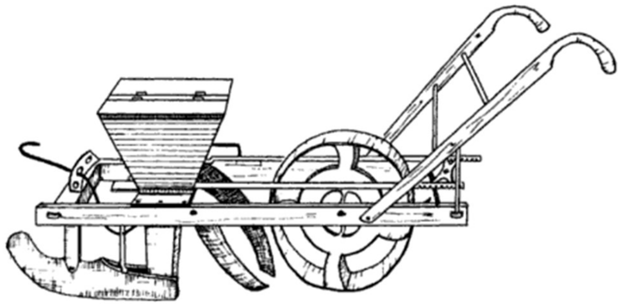

**Figure 2.** Billings' single-row horse-drawn corn planter[12].

The advent of these revolutionary agricultural implements marked a turning point in human history, empowering farmers with the tools and techniques necessary for efficient and productive cultivation. The seamless integration of gears into the seed distribution mechanism and the introduction of advanced seeders not only transformed the efficiency of planting but also paved the way for subsequent advancements in mechanized agriculture.

By delving into the historical evolution of planting technology, we gain valuable insights into the progress made over centuries, serving as a foundation for contemporary innovations in the field of urban development. The lessons learned from the ingenuity of early inventors continue to resonate in the present day as we strive to design and develop sustainable urban farming practices that contribute to food security and the well-being of urban communities. **Figure 2** shows Billing's single-row horse-drawn corn planter.

During the mid-twentieth century, rural innovations and explorations revolutionized the way farmers approached crop planting. One notable development was the adoption of starter fertilizers in corn planting during the 1950s. By spacing the seeds 2½ inches apart and planting them 2½ inches deeper, farmers achieved higher yields at harvest[13]. This innovation prompted the introduction of heavier corn planters equipped with fertilizer and compost attachments, as well as sturdy frames to support the weight. However, these advancements necessitated tractors with sufficient power to efficiently operate the planters[14]. Thus, the evolution of planter technology during the 1950s and 1960s marked a significant shift, driven by new methods that demanded new machines[14].

In the context of maize production, low yields can often be attributed to improper practices in weed control, fertilizer application, diseases, and, most importantly, planting operations[15]. In Bangladesh, for instance, maize is traditionally planted by hand, resulting in the sowing of more seeds per hill than is recommended. This leads to overcrowding, intensifying competition for sunlight, nutrients, and water, and the accumulation of pests[15]. Extensive research has been conducted on the development and evolution of maize planters to address these challenges[16]. By utilizing well-designed planter attachments on 2-wheel tractors, farmers can effectively cultivate larger areas with maize, wheat, pulses, and oilseeds[17]. The introduction of a minimum-tillage planter with an effective field capacity of 0.1 ha/hr has demonstrated significant time and cost savings compared to traditional methods, reducing labor costs and improving efficiency[17]. In Nigeria, seed planting practices still predominantly rely on conventional and manual methods, which can be time-consuming. While tractor-drawn planters are preferred on large farms, animal-drawn planters are considered more economical for small and micro-level operations[18]. Notable contributions have been made in the field of planter development, such as the planter designed, manufactured, and tested by Olajide and Manuwa, which features a seed capacity of 0.36 ha/hr and an effectiveness rate of 71%[19]. Additionally, Kumar (1986) developed a manually operated animal-drawn seeding attachment cultivator with a seed rate of 43.2 kg/hr and a field capacity of 0.282 ha/hr. This innovation showed minimal seed damage and delivered satisfactory performance for crops like wheat and barley[20].

The assessment of a manually operated two-row okra planter, as depicted in **Figure 3**, through field and laboratory tests, revealed a seed rate difference of 4.97% between the two seed containers. The seed rate achieved was 0.36 kg/ha, leading to a significant reduction in rate damage by 3.51%[20]. The Department of Agriculture and Environmental Engineering at the University of Ibadan, Nigeria, played a pivotal role in developing this two-row okra planter. Through continuous advancements in planter technology and agricultural practices, farmers can overcome the challenges associated with planting operations, improve productivity, and enhance overall crop yield.

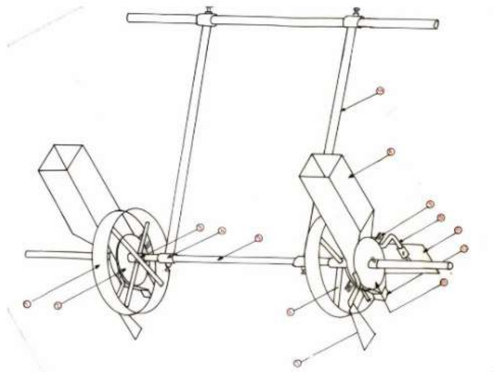

**Figure 3.** Two row Okra planter[20].

As per **Figure 3**, In the domain of agricultural advancement, Gupta and Herwanto (1992) embarked on a project to design and manufacture a direct paddy seeder specifically tailored to match a two-wheel farm vehicle. This notable machine boasted a field capacity of approximately 0.5 ha/hr, operating at a forward speed of 0.81 m/s. Notably, the implementation of the metering instrument ensured that no damage was caused during the seeding process[21]. Building on this progress, Molin and D'Agostin introduced a groundbreaking concept—an adaptable planter engineered for stony terrains. This ingenious design featured 12 radially arranged spades with cam-actuated gates and a plate seed meter. Performance evaluations demonstrated a reduction in human effort, improved seed placement accuracy, and significantly increased field capacity[22].

Recognizing the need for a simple and cost-effective solution, hand planters have gained popularity. These devices, such as the punch planter, offer a straightforward mechanism for entering surface mulch while simultaneously distributing seeds and fertilizer at the required soil depth. The punch planter comprises two shafts, one made of metal and the other of wood, connected to metal bills and carrying handles containers for seed and fertilizer[23]. However, despite the advantages of hand jab planters, they also present certain challenges, including potential clogging of the hole openers, inconsistent seed drop per station, and the inability to drop seeds in certain stations[24]. **Figure 4** illustrates a simple Jab Planter in action.

The effective development and dissemination of agricultural technologies to resource-poor small-scale farmers in Botswana pose a significant challenge[25]. Despite previous efforts by the Department of Agricultural Research in the Ministry of Agriculture, the adoption rate of these innovations remains low. The issue of technology adoption received considerable attention in Botswana during the 1980s[25,26].

**Figure 4.** Showing a Jab Planter[27].

Currently, farmers' acceptance of most existing planters is only partial. While planters have been designed and manufactured in Botswana, taking into account factors such as effectiveness, efficiency, performance, and suitability for the local climate, farmers still struggle with the high cost of purchasing and maintaining farm implements. Manually operated planters are considered more economical and suitable for small-scale farmers compared to tractor-drawn options. However, some locally available donkey-drawn planters are heavy and not durable enough for the semi-arid climate of Botswana. Additionally, certain materials used in existing planters on the market are unsuitable for local conditions and can lead to seed damage.

Therefore, the design of an optimized maize planter that maximizes local maize production is crucial. This study aims to design, fabricate, and test an economical two-row donkey-drawn maize planter specifically tailored to the needs of small-scale farmers in Botswana. The use of a two-row planter allows for higher yields compared to a single-row planter and offers economic benefits while being easily operated by a single person.

Located in the southeastern corner of Botswana, just 15 km from the South African border, Gaborone serves as the capital and largest city[28]. The study involves the modeling of a mechanical planter using "SolidWorks" software, aiming to create a simple, economical, lightweight, and effective solution for domestic maize planting.

This study aims to address the following research questions:

1) How can the design and fabrication of an economical two-row donkey-drawn maize planter contribute to maximizing local maize production?
2) What are the essential features and characteristics required for the successful implementation of a suitable maize planter for small-scale farmers in Botswana?

The current state of agricultural technology adoption in Botswana, particularly in the context of maize planting, presents significant limitations and challenges for resource-poor small-scale farmers. The lack of suitable and affordable maize planters hinders their productivity and limits their potential for economic growth. Therefore, there is a critical need to design and develop an optimized two-row donkey-drawn maize planter that addresses the specific requirements and constraints faced by small-scale farmers in Botswana. This study aims to fill this gap by proposing a solution that is efficient, cost-effective, and tailored to the local agricultural conditions, ultimately contributing to improved maize production and the socioeconomic well-being of small-scale farmers.

## 2. Materials and methodology

In the literature research conducted, a comprehensive analysis of various planter technologies was carried out to gain a thorough understanding of their operational principles. This analysis served as a basis for identifying the most suitable technology to be adopted and adapted for the design of the model. During the selection process, several factors were taken into consideration to ensure the optimal design of the model.

One crucial factor that was considered was the weight of the planter. It was essential to design a lightweight model that could be easily drawn by donkeys, taking into account the limitations of their pulling capacity. This aspect was of utmost importance to ensure the practicality and ease of operation in the field.

Additionally, another vital factor considered during the design process was the incorporation of a mechanism to address the issue of improper seed spacing. Achieving consistent and accurate seed placement is critical for maximizing crop yield. Therefore, the model was designed to include a device or mechanism that would effectively regulate and control the spacing between seeds, ensuring an optimal distribution and reducing the likelihood of overcrowding or uneven planting.

By carefully considering these factors and conducting a thorough literature review, the research team aimed to develop a model that not only meets the specific requirements of donkey-drawn operation but also addresses the challenges related to seed spacing. The subsequent sections of the methodology provide a detailed explanation of the design process, materials used, and testing procedures employed to validate the effectiveness and efficiency of the proposed model.

The design must address certain factors, which include the following:

1) Ensure the design is light enough to be pulled by not more than four donkeys with ease.
2) Simple, compact design with materials easily available and economic.
3) Seeder is self-contained in the hopper.

The design considered different planters available and their qualities, and by so doing, incorporated the optimum solution into the final design as provided in **Table 1**. The final design incorporated existing ideas while working within the constraints of the study.

**Table 1.** Detail of materials for various components of donkey driven planter.

| Component | Material options | Justification |
|---|---|---|
| Seed hoppers | • Aluminum<br>• Mild steel<br>• Stainless steel<br>• Iron | 3-mm-thick aluminum sheets were chosen to make seed hoppers. Good mechanical properties and readily available in Botswana. |
| Furrow openers | • Aluminum<br>• Mild steel<br>• Iron | Mild steel was selected for making furrow openers, as it has good strength with high toughness and high stiffness. Also, because it easy to shape and easy to weld. It should be noted that, as it already stated a planter operates in ready, tilled soil, it experiences less draft force. |
| Seed metering device | • (Teflon) Plastic<br>• Wood | Teflon plastic was chosen since it has low friction quality. This implies that moving parts made of Teflon will slide easily, causing less warmth, less wear and tear. |
| Runner wheels | • Mild steel<br>• Aluminum<br>• Stainless steel<br>• Iron | Mild steel was selected for making runner wheels has good strength with high toughness and high stiffness. |
| Frame | • Mild steel<br>• Aluminum<br>• Stainless steel<br>• Iron | Mild steel was selected to be used for the frame due to good mechanical properties and readily available in Botswana |
| Handle | • Mild steel<br>• Aluminum<br>• Stainless steel<br>• Iron | Mild steel was selected because of its favorable combination of properties, including good machinability, weldability, and affordability. Additionally, mild steel exhibits sufficient strength and durability for the intended application, making it a practical choice for both the frame and handle to ensure uniformity in material characteristics throughout the component. |

## 2.1. Design of a seed hopper

The exterior of the seed hopper is constructed using thin sheet metal, forming a cubic shape with sides measuring 200 mm. The interior design of the hopper is shaped like a frustum of a pyramid, facilitating the smooth flow of seeds towards the seed metering mechanism located at the base of the hopper. **Figure 5** provides a visual representation of the seed hopper design sketch.

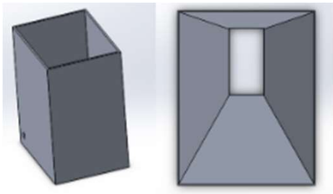

**Figure 5.** Design of hopper.

The volume of the seed hoppers is calculated as follows:

$$V_1 = (\frac{h}{3})(A1 + A2 + \sqrt{A1 + A2})$$

$$V_1 = (19.7)((2.9 \times 5.5) + (11.4 \times 14.4) + \sqrt{}(15.95 + 164.16))$$

$$V_1 = (19.7)\big((180.11) + (13.421)\big) \quad (1)$$

$$V_1 = 3812.55 \text{ cm3}$$

$$height, h = tan\emptyset = \frac{O}{A}$$

This is the vertical height of the interior frustum of the pyramid design from the base of the seed hopper. Hence the volume of the frustum, $V_1$ is calculated as; $V_1 = 3812.55$ cm$^3$. The volume of the remaining section of the seed hopper, $V_2$ is the volume of a cuboid with a square cross-section and a height of 20 − 4.62 = 15.38 cm.

$$\text{V2 (of cuboid)} = \text{L} \times \text{w} \times \text{h} = 12 \times 15 \times 20 = 3600 \text{ cm3} \quad (2)$$

Total volume (the total capacity of the hopper), $V$ is the sum of the two; $V = V_1 + V_2 = 3812.55$ cm$^3$ + 3600 cm$^3$ = 7412.55 cm$^3$. Mass estimation of seed hopper material

$$M_{hm} = \rho_{hm} \times V_{hm} \quad (3)$$

where $M_{hm}$= hopper material mass; $\rho_{hm}$ = density of hopper material; $V_{hm}$ = volume of hopper material.

$$V_{hm} = TSA \times thickness \quad (4)$$

where $TSA$ = total surface area.

$$TSA = 4a^2 + (a^2 - b \times c) + \left[(\frac{1}{2}(a + b)h_1 + \frac{1}{2}(c + a)h_2\right]$$

$$TSA = 4 \cdot 20^2 + (20^2 - 4 + 1.6) + \left[(\frac{1}{2}(20 + 4)10.29 + \frac{1}{2}(1.6 + 20)9.24\right] TSA = 2341.44cm^2$$

$$V_{hm} = TSA \times thickness \quad (5)$$

$$V_{hm} = 2341.44 \times 0.3$$

$$V_{hm} = 705.432cm^3$$

Density of aluminum=2.7 g/cm$^3$. Therefore, estimated mass = Vol × Density = 705.432 cm$^3$ × 2.7 g/cm$^3$ = 1904.67 g = 1.9 kg, for two hoppers mass becomes 3.8 kg.

### 2.2. Design of the seed metering device

Diameter of pressing wheel ($D_1$) = 30 cm; Diameter of the seed metering mechanism ($D_2$) = 10 cm.

$$\text{Circumference of drawing wheel} = \pi D\pi \times 30 = 94.25\ \text{cm} \tag{6}$$

Hence for every revolution ground distance covered is 94.25 cm. Since intra-row spacing of feed is between 25–32 cm[29]. The number of seed cells required to be drilled on the seed metering device are calculated as follows:

$$\frac{circumference}{intra-row\ spacing} = 94.25\text{cm}/25\text{cm} = 3.77\text{cells} \tag{7}$$

which is rounded up to 4 cells. Simultaneously to proof 94.25 cm/4 = 23.6 cm ≈ 24.0 cm hence 4 holes are ideal.

$$The\ volume\ of\ the\ metering\ device = \frac{\pi d^2}{4}\times\text{thickness } \pi(7)(7)/4\times 2.5 = 96.21\ \text{cm}^3$$

Density of Teflon = 2.2 g/cm$^3$

Estimated mass = Volume × Density = 96.21 × 2.2 g/cm$^3$ = 211.66 g = 0.21166 kg for two metering devices mass becomes 0.4233 kg. The seed metering device is shown in **Figure 6**.

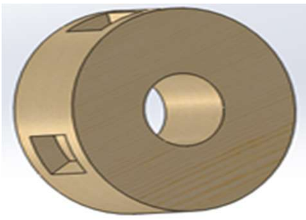

**Figure 6.** Seed metering device.

### 2.3. Design of runner wheels

$$V_1 = \frac{\pi}{4}(30_2^2 - 26_1^2) \times 3 = 527.8$$
$$V_2 = 1.3 \times (26 - 6.7) \times 6 = 150.54$$
$$V = V_1 + V_2 = 678.34$$

Density of mild steel =8.05 g/cm$^3$; estimated mass=Volume × Density = 678.34 cm$^3$ × 8.05 g/cm$^3$ =5460.6 g; number of wheels is two, therefore twice the mass becomes =10.9 kg.

### 2.4. Design of frame

$$V_1 = 2(L \times W \times H) = 2(4\ \text{cm} \times 4\ \text{cm} \times 90\ \text{cm}) = 2(1440\ \text{cm}^3) = 2880\ \text{cm}^3$$

$$V_2 = 4(30\ \text{cm} \times 4\ \text{cm} \times 4\ \text{cm}) = 1920\ \text{cm}^3$$

$$V = V_1 + V_2 = 2880 + 1920 = 4800\ \text{cm}^3$$

Density of mild steel= 8.05 g/cm$^3$; estimated mass = 4 800 cm$^3$ × 8.05 g/cm$^3$ = 38.644 kg

### 2.5. Design of the handle

$$V_{ol} = V_1 + V_2 + V_3 = (70 \times 2) \times 2 + (36 \times 4) \times 2 + (127 + 138.6) \times 2 \times 2 = 1630.4\ \text{cm}^3$$

Estimated mass = 1630.4 cm$^3$ × 8.05 g/cm$^3$ = 13.12 kg

Total estimated mass = 13.12 kg + 38.644 kg + 10.9 kg + 0.4233 kg + 3.8 kg = 66.8 kg

According to the McGraw-Hill Dictionary of Scientific and Technical Terms[30], the power output of a single donkey is approximately 250 watts, which is roughly equivalent to ⅓ horsepower. Considering the soil conditions, the weight of the implement, and the desired working depth, it is crucial for the animal(s) to exert a force equal to or greater than the total resistance or draft requirement of the task for an extended duration[15,31,32]. For an implement operating on untilled soil, such as a plow, an average donkey weighing 165 kg can effectively pull a load that is 12 to 14% of its body mass[30]. Taking 12% of its mass into account, it can successfully pull a plow of 12/100 × 165 kg = 19.8 kg. Therefore, for a planter of 66.8 kg.

$$No. of\ donkeys = \frac{mass\ of\ planter}{19.8Kg} = \frac{66.8}{19.8} = 3.37\ (or\ 4\ donkeys) \tag{8}$$

The developed planter features a main frame constructed using a 20 mm × 20 mm mild steel square tube, providing the necessary strength and rigidity to support the weight of all connected components. The seed hoppers are made of 3 mm thick galvanized steel, marked, formed, and riveted together for durability. A manual bending machine is employed for shaping, while rivets and a riveting gun are used for assembly, resulting in sturdy seed hopper boxes.

For the seed metering device, a 30 mm-diameter wooden rod is utilized, featuring four equidistant holes for seed dispensing. A machined mild steel rod, produced using a lathe machine, serves as the connecting shaft for the rotating wheels. The wooden seed metering mechanism is attached to the shaft, allowing seeds to be scooped and dispensed onto the ground as the wheels rotate.

The hopper and handle are securely connected to the main frame through welding, ensuring a stable attachment. Furrow openers and furrow closers are affixed to the main frame using bolts and nuts, allowing for easy detachment and adjustment as required.

The row-to-row spacing maintained by the developed planter is not specified in the provided information. Additionally, plant-to-plant spacing is not explicitly mentioned in the text. To determine these values, further details about the specific design and configuration of the planter would be needed. If you have additional information, I’d be happy to help with any specific questions you may have.

By employing these construction methods and materials, the planter was designed to be durable, functional, and easily adjustable to suit different planting requirements.

## 3. Result and discussion

The construction of the planter model involved a step-by-step process of cutting, forming, and welding the individual parts. These parts were then assembled using bolts, nuts, and rivets where necessary to ensure a secure and sturdy structure. The orthographic view of the design can be observed in **Figure 7**, providing a detailed representation of the planter’s dimensions and features. Additionally, **Figure 8** depicts an exploded view of the assembly, highlighting the arrangement and relationship of the various components.

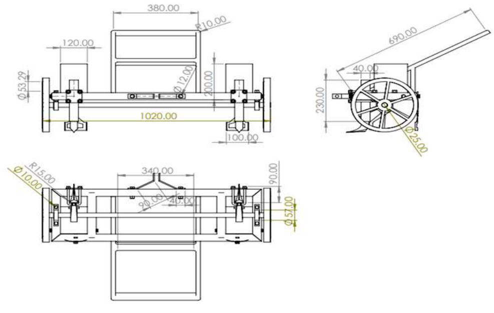

**Figure 7.** Orthographic view of the developed planter from solid works design.

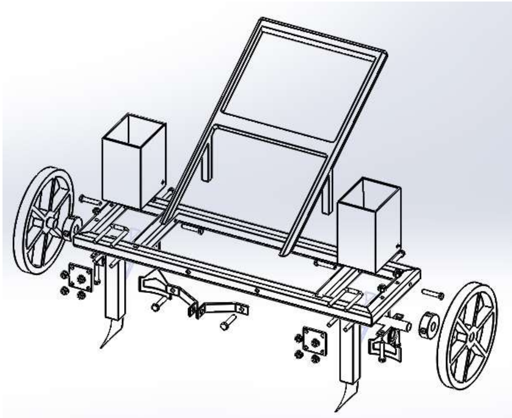

**Figure 8.** Exploded view.

**Figure 9** presents the total mass of the entire planter assembly, which was calculated using "SolidWorks". The obtained results indicate that the actual mass is lower than the estimated numerical value of 66.8 kg. Consequently, based on Equation (8), the designed planter with a mass of 48.93 kg corresponds to 2.47 donkeys, rounded up to 3 donkeys.

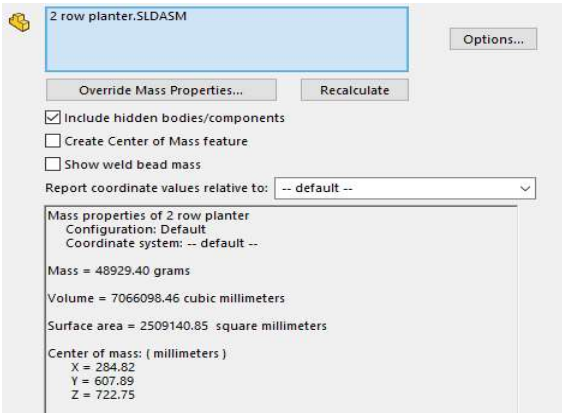


**Figure 9.** Mass properties of the planter.

Since the planter operates on pre-tilled soil, the overall draft force exerted on the planter is reduced. As a result, the pulling force required for the planter is expected to be lower, indicating that it can be pulled with ease. After analyzing the estimated mass from "SolidWorks", it was determined that the number of required donkeys decreased to 3, compared to the initial estimation for the planter's mass.

**Figure 10.** Constructed two-row single metering plate maize planter.

The fabricated model in **Figure 10** accurately reflected the design depicted in "SolidWorks" and successfully demonstrated the operational principle of the planter through the implemented metering device. However, there were variations in the materials used for the model compared to those initially chosen for the designed planter to minimize the overall cost of the model. Additionally, slight modifications were made to the handle and frame design, aiming to reduce the amount of material used and ensure cost-effectiveness.

## 4. Conclusion

In conclusion, this study successfully addressed the objective of designing and fabricating a two-row donkey driven maize planter using "SolidWorks" design software. The model created accurately represents the intended structure and incorporates locally accessible materials to optimize cost efficiency. The key finding of this study is the achievement of a lightweight planter, weighing approximately 48.93 kg, which can be easily operated by three donkeys. The use of low-weight materials and minimalistic design principles contributed to the reduced weight and improved practicality of the planting process. However, it is important to acknowledge the limitations of this research. The materials used in the fabricated model differed from the original design, primarily to minimize costs. While efforts were made to maintain the integrity of the planter's functionality, further optimization could be explored to enhance durability and performance.

To validate the effectiveness of the designed planter, it is recommended to conduct field testing and gather feedback from farmers and agricultural experts. This would provide valuable insights into its real-world applicability, addressing factors such as planting accuracy, efficiency, and adaptability to different soil conditions.

Furthermore, the scope of this research can be expanded in the future to include the planting of other crops using the same implement. By incorporating modifications and additional attachments, the planter can be adapted to suit the requirements of various agricultural practices, thereby maximizing its utility for small-scale farmers.

In terms of advantages, the designed planter offers several benefits. Its lightweight nature reduces the burden on animals and enables easy maneuverability in the field. The cost-effective design ensures affordability for resource-constrained farmers. By streamlining the planting process, it contributes to increased efficiency and productivity in maize cultivation. In summary, this research lays the foundation for the development of an effective and economical two-row donkey-drawn maize planter. While further improvements and field testing are necessary, the current findings demonstrate its potential to revolutionize small-scale farming practices. By addressing the limitations, exploring new crops, and refining its design, this planter has the potential to make a significant impact on agricultural productivity and rural livelihoods. Collaboration with local farmers, agricultural experts, and manufacturers is essential to refine the design based on their practical insights and ensure widespread adoption. Moreover, the potential environmental impact of the planter, including fuel efficiency and emissions reduction, warrants investigation. The research serves as a foundation for further advancements in agricultural machinery tailored to the specific needs and resources of the region, contributing to sustainable agricultural practices and improved food security.

## Author contributions

Conceptualization, OMS and AA; methodology, UM; software, MM; validation, OMS, AA and UM; formal analysis, MM; investigation, UM; resources, MM; data curation, UM and MM; writing—original draft preparation, AA; writing—review and editing, OMS; visualization, UM; supervision, OMS and AA; project administration, OMS and AA; funding acquisition, UM. All authors have read and agreed to the published version of the manuscript.

## Conflict of interest

The authors declare no conflict of interest.

# References


1. Soyoye BO, Ademosun OC, Agbetoye LAS. Determination of some physical and mechanical properties of soybean and maize in relation to planter design. *Agricultural Engineering International: CIGR Journal* 2018; 20(1): 81–89.
2. Mkomwa S, Kaumbutho P, Makungu P. Farm machinery for conservation agriculture. In: Farooq M, Siddique K (editors). *Conservation Agriculture*. Springer; 2014. pp. 109-131. doi: 10.1007/978-3-319-11620-4_5
3. Rajavel S, Rajeshkumar R, Pramjin P, et al. Design and fabrication of seed in planter by conversion of energy. *International Journal of Engineering Research & Technology* 2018; 6(4): 4–7. doi: 10.17577/IJERTCONV6IS04085
4. Soyoye BO. Design and evaluation of a motorized multi-grain crop planter. *Agricultural Engineering International: CIGR Journal* 2020; 22(1): 54–66.
5. García de Jalón S. Participatory process: Approaches for assessing farmer behavior towards adopting climate change adaptation strategies in Sub-Saharan Africa. In: Quiroga S (editor). *Economic Tools and Methods for the Analysis of Global Change Impacts on Agriculture and Food Security*. Springer; 2018. pp. 61-86. doi: 10.1007/978-3-319-99462-8_5
6. Eke CNU, Asoegwu SN, Nwandikom GI. Some physical properties of jackbean seed (*Canavalia Ensiformis*). *Agricultural Engineering International: CIGR Journal* 2017; 1: 1–11.
7. Abebe F. Development and evaluation of animal-drawn. *Single Row Tillage-Cum-Multicrop Planter* 2018; 6: 500–508. doi: 10.14662/ARJASRD2018.083
8. Moepeng P. Rural development in Botswana: Experiences from elsewhere and emerging issues. Available online: https://ageconsearch.umn.edu/record/152685/?v=pdf (accessed on 2 May 2023).
9. Ricci T. Jethro Tull. Available online: https://www.asme.org/topics-resources/content/jethro-tull (accessed on 2 May 2023).
10. Kubik R. *How to Use Implements on Your Small-Scale Farm*. Voyageur Press; 2005.
11. Valavanidis A, Vlachogianni T. *Homo sapiens*' energy dependence and use throughout human history and evolution. Available online: https://www.researchgate.net/publication/303370977_Homo_Sapiens'_Energy_Dependence_and_Use_Throughout_Human_History_and_Evolution (accessed on 2 May 2023).
12. Charles V. *Mapes. Illustrated Catalogue of Plows, and Other Agricultural Implements and Machines*. M'Crea & Miller; 1861.
13. Ganzel B. Planter technology. Available online: https://livinghistoryfarm.org/farminginthe50s/planter-technology/ (accessed on 2 May 2023).
14. Ganzel B. Planter technology. Available online: https://livinghistoryfarm.org/farminginthe50s/machines_10.html (accessed on 2 May 2023).
15. Rabbani MA, Hossain MM, Asha JF, et al. Design and development of a low-cost planter for maize establishment. *Journal of Science Technology and Environment Informatics* 2016; 4(1): 270–279. doi: 10.18801/jstei.040116.30
16. Zhao Y, Xing S, Zhang Q, et al. Causes of maize density loss in farmers' fields in Northeast China. *Journal of Integrative Agriculture* 2019; 18(8): 1680–1689. doi: 10.1016/s2095-3119(18)62101-x
17. Mosmar S, Ah-mmed A, Maize I. Design and development of a power tiller operated inclined plate multi-crop planter. *Journal of Agricultural Engineering* 2004; 31(1).
18. Ani O, Uzoejinwa B, Anochili N. Design, construction and evaluation of a vertical plate maize seed planter for gardens and small holder farmers. *Nigerian Journal of Technology* 2016; 35(3): 647. doi: 10.4314/njt.v35i3.25
19. Gbabo IA, Simeon M. Design, fabrication and testing of a tractor drawn soybean planter. *FUW Trends in Science & Technology Journal* 2017; 2(1B): 562–568.
20. Bamgboye AI, Mofolasayo AS. Performance evaluation of a two-row okra planter. *Agricultural Engineering International: CIGR Journal* 2006; 1–10.
21. Khan K, Moses SC, Kumar A. The Design and fabrication of a manually operated single row multi-crops planter. *IOSR Journal of Agriculture and Veterinary Science* 2015; 8(10): 2319–2372.
22. Edeh J, Johnson I. Development and performance evaluation of a manually operated cowpea precision planter. *International Journal of Engineering and Technology* 2014; 4(12): 693–699
23. Bonsu PO, Omae H, Nagumo F, et al. Evaluation of two jab planters for planting maize in the forest zone of Ghana. *International Journal of Innovation and Applied Studies* 2015; 10(1): 30–35.
24. Food and Agriculture Organization of United Nation. *Animal Traction and Single-Axle Tractor Drawn Planters in Conservation Agriculture*. Food and Agriculture Organization of United Nation; 2014.
25. Acquah BK. Making technologies work for resource poor farmers Botswana. *Botswana Journal of African Studies* 2003; 17(2): 78–84.
26. Obingene MC. *The Role of Extension Workers in the Provision of Information to Small-Scale Crop Farmers in Oji-River Local Government Area, Enugu State, Nigeria* [Master's Thesis]. University of Botswana; 2015.

27. Teca. Jab planter user manual. Available online: https://teca.apps.fao.org/teca/fr/technologies/7339 (accessed on 2 May 2023).
28. Agarwal A, Seretse OM, Letsatsi MT, Dintwa E. Review of energy status and associated conservational issues in Botswana. *Matec Web of Conferences* 2018; 172. doi: 10.1051/matecconf/201817206003
29. Michael D, Orzolek, Donald R. Effect of planting equipment and techniques on seed germination and emergence: A review. *Association of Official Seed Analysts and the Society of Commercial Seed Technologists* 1984; 9(2): 99–113.
30. Lapedes DN. *Mcgraw-Hill Dictionary of Scientific and Technical Terms*, 2nd ed. Mcgraw-Hill; 1978.
31. Robert W. *Technical Note 21. Soil, Draft, and Traction*. Agrospere International Group; 2016.
32. Ali M. Design and development of a multi-crop manual seed drill. *Agricultural Engineering International: CIGR Journal* 2019; 21: 51–60.