DEVELOPMENT OF A FOUR-ROW TRACTOR MOUNTED SOYBEAN PLANTER

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MAY, 2023

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A DISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES,

AHMADU BELLO UNIVERSITY IN PARTIAL FULFILLMENT FOR THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE DEGREE IN AGRICULTURAL ENGINEERING

DEPARTMENT OF AGRICULTURAL AND BIO-RESOURCES ENGINEERING,

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DECLARATION

I declare that the work in this dissertation entitled "Development of a Four-Row Tractor Mounted Soybean Planter" has been performed by me in the Department of Agricultural and Bio-Resources Engineering. The information obtained from the literature has been properly acknowledged in the text and a list of references provided. No part of this Dissertation was previously presented for another diploma or degree at this or any other institution.

FARUK HAMMANADAMA ABUBAKAR	________________	________________
Name of student	Signature	Date

CERTIFICATION

This dissertation entitled “DEVELOPMENT OF A FOUR-ROW TRACTOR MOUNTED SOYBEAN PLANTER” by FARUK HammanadamaAbubakar met the regulations governing the award of the degree of Masters of Science in AgriculturalEngineering of the Ahmadu Bello University, and is approved for its’ contribution to knowledge and literary presentation.

Prof. M. L. SuleimanChairman Supervisory CommitteeSignature Date

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ACKNOWLEDGEMENT

This research work was done with the assistance of Allah and some great people that are hereby acknowledged for their various contributions. With pleasure, I wish to express my profound praise and adoration to Almighty Allah (S.W.A) for blessing us with strength, wisdom and resources needed in actualization of this research work. All glory and adoration is due to Allah, the most Beneficent and the most Merciful. All praise on Prophet Muhammad SallalahuAlaihiWassalam, the best of mankind.

I extend my special appreciation to my supervisory team Prof. M. L. Suleiman and Dr. AminuSaleh, for their remarkable contributions and encouragement, time, and advice toward the success of this research. My Allah reward you abundantly.

In the same vein, I am greatly indebted to the Head of Department Prof. M. Isiaka, and all the academic staff in the departmentfor their competency in imparting knowledge and dignify morality. In no small measure, I wish to appreciate all staff of the Departmental workshops for their kind corporation, caring and valuable idea in the course of the research.

I wish to seize this opportunity to appreciate the unreserved effort of my parents, Adamawa State Polytechnic, Tertiary Education Trust Fund (TETFUND) and my siblings, my friends Bashar Bakari, Mustafa AbubakarMaizare toward my general wellbeing and especially in the success of this work. Their parental advice, encouragement and supports are indeed greatly acknowledged. May Allah continue to bless them abundantly. I also, appreciate my wife Shafa'atuMisa, my daughter Fatima Hammanadama who always care and been patience while caring out the research. Your unrelenting effort is recognized. My Allah bless you all.

To my friends and colleagues, I deeply recognized your cooperation, unrelenting inputs, unending hope and encouragement toward the academic pursuit. Hopefully, Allah shall crown our effort peacefully and abundantly. Finally, I am using this medium to extend my kind appreciation to those who in one way or the other contributed to the success of this work. Thank you all, and God bless you.

ABSTRACT

The traditional method of planting soybean in Nigeria does not result in obtaining maximum yield of the crop per unit area. This is due to either incorrect number of plants per stand, inter-row spacing or intra-row spacing. This research work is embarked upon to develop a four-row tractor mounted precision soybean planter in order to address these challenges.The planter was designed, fabricated (in the months of June, July, and August, 2021) and evaluated in theDepartment of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Zaria Nigeria, during 2021 raining season. The planter has functional unitsoffour hoppers, four seed metering units, four press wheel, four delivery chutes, four furrow openers, and four soil covering devices. The individual planting units werearranged on the main frame at inter-row spacingof 50 cm as recommended by the agronomic practices of planting soybeans.The developed planter was evaluated both laboratory and on the field in terms of planting speed, seedling emergence, intra-row spacing, seed delivery rate, number of seeds per hole and percentage seed damage. The laboratory calibration test of the planter shows that it can deliver one (1) single seed per hole of soybeans (TGX 1951-3F) variety and 1.4% seed damage. The developed planter was mounted at the three-point linkage of the tractor (EICHER, Model: 5660, 50 hp) rear end; soybean seeds was poured in to the hopper. The tractor was set to 7 km/h, 10 km/h and 15 km/h and at 2 cm and 4 cm depth of planting and operated. A tractor forward speed of 15 km/h at 2 cm depth of planting produced the best combination in terms of seed emergence. The intra-row spacing averages 5.7 cm, and 50 cm inter-row spacing with an estimation of 400,000 plants per hectare. The results obtained from the field showed that the seed delivery rate was 48.2kg/ha, effective field capacity of 1.14 ha/hand field efficiency of 76.6%. These results indicate that the developed planter could plant 1 seed of soybean variety (TGX 1951-3F) per hole, efficient, affordable for optimum soybean plant population per hectare.

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LIST OF ABBREVATIONS, UNITS AND SYMBOLS

Abbreviations

ANOVA : Analysis of variance
ASAE : American Society of Agricultural Engineers
CV : Coefficient of variance
d.f. : Degrees of freedom
d_w : Diameter of the ground wheel
FAO : Food and Agriculture Organization of the United Nations
GDP : Growth domestic product
IAR : Institute for Agricultural Research
IITA : International Institute for Tropical Agriculture
NCRPS : National Coordinated Research Council Project on Soybean
P_s : Actual number of seeds discharged
RCBD : Randomized completely block design
S_c : Intra row spacing
W : Weight of the planter

Units

°C : Degree centigrade
cm :Centimetre
g : gram
h : hour
ha : hectare
ha/h : hectare per hour
i.e. : that is
kg : Kilogram

kg/ha	:	kilogram per hectare
km/h	:	kilometer per hour
m	:	Meter
mm	:	Millimetre
rpm	:	Revolutions per minute
s	:	Second
t/ha	:	Tonnes per hectare

Symbols

%	:	percentage
√	:	Square root
θ	:	Theta
π	:	Pi
τ	:	Tau
ω	:	Omega

CHAPTER ONE

INTRODUCTION

1.1 Backgroundof the Study

Soybean (*Glycine max* L.) belongs to the family*Fabaceae* sub-family *Faboideae*. It is one of the major oil seed crops of the world. Among the leguminouscrop's soybean contains high amount of protein (40-42%) and oil (18-20%) and a good amount of other nutrients like calcium, phosphorus, iron and vitamins (Muzammal*et al*.,2014*)*. Generally, human consumes protein from plant and animal sources. Many people in Nigeria cannot afford animal protein like egg, milk, meat and fish in their daily diet because of their cost (Wahab*et al*.,2002). Therefore, soybean can play a vital role to supplement protein in their diet.

The rapid growth in the poultry sector in the past few years has also increased the demand for soybean production in Nigeria. It is believed that soybean production will increase as more farmers become aware of the potential of the crop, not only for cash and food but also for soil fertility improvement as they fix atmospheric nitrogen and thus reducing fertilizer usagein the plants(Dugje*et al.*,2009).

Due to the high cash value and relative ease of cultivation, soybean production in Nigeria is steadily increasing and, Nigeria alone accounted for 43% of Africa's total production in 2008 (Biam and Tsue, 2013). In 2020, the production of soybean in Nigeria was estimated to be 368 thousand metric tons. Between 2010 and 2020, the soybean production in the country increased, registering the highest growth in 2011, when the production grew by about 25 percent in 2011 compared with the previous years.In 2020, the production remained stable and registered a growth of 385 thousand metric tons against 2019 (Simona, 2020). Based on the increasing production of soybean in Nigeria, there is a need for the production of a precise soybean tractor mounted planter that can complement this effort to ensure a stable production system.

Manual method of seed planting results in shallow seed placement, difference in plant spacing problem and fatigue on the farmer which limits the size of the field that can be planted. Planting machines are needed to increase soybean production but small holder farmers still continue to plant manually leading to low productivity (Kalay*et al*.,2015). Therefore, appropriate soybean planter that would reduce drudgery and enable small-holder-farmers to produce more soybean in an environmentally friendly condition need to be developed,(Bamgboye and Mofolasayo, 2006). In Nigeria, different multi-crop planters have been developed in the past with various prototype advantages. However, there are disadvantages associated with them.

1.2 Statement of the Research Problem.

The traditional method of planting soybean does not result in obtaining maximum yield of the crop per hectare. This is due to either incorrect number of plants per stand, inter- row spacingor intra-row spacing.

Manual planting which is tedious, time consuming, expensive and labouros, would hardly result in obtaining the ideal conditionfor obtaining maximum yield, at the end of the day, the optimum plant population is hardly obtained.

At the moment in Nigeria there are few specialized planting equipment (machine) suitable for obtaining the ideal or optimum plant population per area of soybean as recommended by International Institute of Tropical Agriculture (IITA) 2020 that is locally produce.

Therefore, there is a need to develop a four-row tractor mounted precision soybean planter to improveits production in Nigeria.

1.3 Aim and Objectives of the Study.

The aim of this research work was to developed a four-row tractor mounted soybean planter suitable for planting commonly grown soybean (TGX1951-3F) variety in Northern Nigeria using locally available materials.

The specific objectives of the study were to:

i. design a four-row tractor mounted soybean planter
ii. fabricate the four-row tractor mounted soybean planter using locally available materials.
iii. evaluate the performance of the planter both in the laboratory and on the field, with the commonly grown soybean variety (TGX1951-3F).

1.4 Justificationof the Study

When the four-row tractor mounted soybean planter is developed,the following benefits stand to be obtained:

A planter that can plant soybean at the optimum plant population per hectare, which in turn can give maximum yield of soybeans per hectare. A simple and easy to operate and maintained soybeans planter would be obtained that is affordable to the medium and large-scale farmers and entrepreneurs and subsequently increase income of the farmers and entrepreneurs working on the value chain of Soybeans which will boost the Gross Domestic Products (GDP) of the country.

1.5 The Scope of the Study

The scope of this research was to develop a four-row tractor mounted soybean planter and evaluate its performance both in the laboratory and on the field with soybean variety (TGX1951-3F).

CHAPTER TWO

LITERATURE REVIEW

2.1 Crop Propagation

Crop propagation is the introduction of seeds to the ground or on predetermined rows or on at specific depths and spacing. Some seeds are usually planted in drilled rows, 15 to 36cm apart in what is referred to as solid planting (Kepner*et al*., 1982, Bosoi*et al.*, 1988 and Srivastava*et al.,*1993). Certain cereals (such as rice) can be planted by broadcasting. Other than this, crops are planted in rows on un-prepared soils, soils subjected to primary tillage or soils subjected to primary and secondary tillage (such as ridges). When planting is done in rows on ridges, such is referred to as "bed planting" (Kepner*et al*., 1982).

2. 2 Varieties of Soybean.

Table 2.1: Recommended soybean varieties for Guinea savanna ecological zones in Nigeria

Variety	Ecology	Characteristics	Appropriate planting time
TGX 1448-2E	Southern and Northern Guinea savanna	Late maturing, high yield, low shattering, high oil content, and excellent grain color. Good for Striga control.	In weeks 2–3 of June in NGS and week 1 of July in SGS.
TGX 1951-3F	Southern and Northern Guinea savanna	Medium maturing, high yield, low shattering, high oil content, and excellent grain color. Tolerant to rust, Cercospora leaf spot, bacterial pustule, and poor soils. (2.5 t/ha).	In weeks 3–4 of June in NGS and week 1 of July in SGS
TGX 1904-6F	Southern and Northern Guinea savanna	Medium maturing, high yield, low shattering, high oil content, and excellent grain color. High fodder yield and resistant to lodging, Cercospora leaf spot, and bacterial pustule. (1.5 - 2 t/ha).	In weeks 2–3 of June in NGS and week 1 of July in SGS.

TGX 1987-62F	Sudan savanna	Early maturing, average yield, medium shattering, good oil content, and fair grain color. Highly resistant to rust, Cercospora leaf spot, and bacterial pustule. (2.1 t/ha).	In week 4 of June to week 1 of July.
TGX 1987-10F	Sudan savanna	Early maturing, average yield, medium shattering, good oil content, and fair grain color. Highly resistant to rust, Cercospora leaf spot, and bacterial pustule. (1.5–2 t/ha).	Week 4 of June to week 1 of July
TGX 1835-10E	Sudan savanna	Early maturing, average yield, low shattering, good oil content, and excellent grain color. Highly resistant to rust, Cercospora leaf spot, and bacterial pustule. (1.5–2 t/ha).	Week 4 of June to week 1 of July

N.B. Early and extra-early maturing varieties are strongly recommended for the Sudan savanna because of the low amount and duration of rainfall in the zone

IITA, 2020.

2.3 Mechanical and Physical Properties of Soybean

Soyoye*et al*. (2018) conducted a research on the physical and mechanical properties of a soybean varietyand was reported as in Table 2.2

Table 2.2: Values of the physical properties of soybeans (TGX 1987-10F)

Property	Number of samples	Maximum	Minimum	Average	Standard Deviation
Length, cm	100	0.9	0.64	0.737	0.046
Width, cm	100	0.755	0.25	0.627	0.056
Thickness, cm	100	0.57	0.39	0.468	0.039
Geometric mean diameter, cm	100	0.729	0.433	0.6	0.041
Surface area, cm^2	100	1.669	0.59	1.135	0.151
Roundness	100	1.825	1.391	1.579	0.089
Sphericity	100	0.869	0.619	0.814	0.031
Bulk mass, g	10	19.013	16.012	17.732	0.923
Bulk volume, mL	10	18	14	16.6	1.35

Bulk density, g mL-1	10	1.144	1.006	1.071	0.05
True density, g mL-1	10	1.162	1.019	1.087	0.053
Porosity, %	10	1.715	0.948	1.397	0.27

Soyoye et al., 2018

2.4 Agronomic Requirements for Crop Establishment and their Implications on Planting

Planting to be agronomically proficient, certain physical requirements apart from *in-situ* soil conditions must be met. There are agronomic requirements for germination, for emergence and for crop establishment. The agronomic requirements for germination include; seed factors (seed quality and pre-sowing treatments on the seeds) and environmental factors. These have implications for planter performance. The implications of the agronomic requirements for germination on aspects of planter performance are:seed quality and pre-sowing treatments on the seeds

2.4.1 Seed factors

Seed quality has major implications for seed metering devices. Substantial increases in planting rate to compensate for low seed viability can impair the performance of seed meters, particularly precision seed metering devices (Murray, 2006). Variations in seed size and shape can also influence planter performance. Some precision seed metering systems (plate type) require uniformity in both size and shape for optimum performance; others (vacuum disc type meters) will tolerate a range of seed size and shape without a significant reduction in metering performance (Zulin*et.al*.,1991). Norris (1982) concluded that:

i. seed damage increases with meter speed and/or seed size;

   i. seed meter performance is reduced as meter speed and/or seed size increases, and

   ii. the maximum recommended operating speed of vacuum and finger pick-up units severely limits operating speed when planting large seeds, such as peanuts, at the recommended spacing. Pre-sowing seed treatments can improve or impair seed metering performance.

2.4.2 Environmental factors

Planter soil-engaging components have a major influence on optimizing environmental factors for germination. To optimize moisture availability to the germinating seed, the planter must open a furrow, place the seedsin the furrow, cover the seed and firm the seedbed. Opening a furrow enables the seed to be planted at adepth where moisture conditions are generally more favourable than those at the soil surface. It is ofparticular importance in regions where high evaporation rates after rainfall promote rapid drying of the surface layer (Maiti and Carrillo-Gutierrez, 1989 as in Murray 2006). Covering the seed and firming the soil around ithelps to stabilize temperature and moisture availability conditions, and protects the seed from predatorssuch as birds and ants. The degree of soil disturbance in the seed zone during the furrow opening process has a major influenceon moisture availability to the germinating seed. The nature and degree of disturbance is largely afunction of furrow opener design (Dickey*et al.*,1994). When crop establishment is the first priority,the degree of disturbance should be restricted to that necessary to obtain sufficient tilt to help cover the seed and ensure sufficient seed/soil contact. Opener design should be such that the seed is placed in or on the moist soil at the base of the furrow anddry soil is not placed immediately on the top of the seed during the covering phase.

2.4 Planters and their Classifications

Planting machinery are broadly classified according to: the number of rows planted in one pass of the machine, the method of attachment to and the power source used to propel the planter and the type of planting machine based on the resultant planting pattern (Murray *et al.*,2006). The number of rows planted is specified by the number of furrow openers that the planter has, hence we can have single-row as in plate 2.1, 2-row, 4-row and so on.

Plate 2.1: IAR single row animal drawn planter (IAR, 2006)

On the basis of power source, a planter could be classified as manual planter (human operated), animal drawn or mechanically powered planter. Planters' type with respect to their planting pattern are classified as; broadcast planter in Plate 2.2, drill planter in Plate 2.3, precision planter in Plate 2.4.

Plate 2.2: Broadcast planter (Murray *et al.*, 2006)

Plate 2.3: Twelve-rows-drill planter (Murray *et al.*, 2006)

Plate 2.4: Single-row precision planter (Murray *etal.*, 2006)

2.5 Review of Existing Planters

Planters with various performance levels have been developed by other researchers, include manual type, animal drawn, self-propelled and tractor mounted planters.

Parish *et al.* (1999) designed, constructed and tested the prototype of belt metering seeder for soybeans planter and compared it with commercially available seeders equipped with fluted, brush, or finger metering systems. At ground speeds of 3.2 to 9.6 km/h, the prototype set for nominal spacing of 2.4 cm was able to meter soybeans with the mean spacing of 2.3 to 3 cm and quality of feed index of 38 to 46%. Seeding uniformity of the prototype was not better than the seeding uniformity of the three commercial seeders.

A sensor based on a light interference technique for sensing the seed flow from the metering mechanisms of seed drill and planter was developed by (Raheman and Singh, 2003). The sensor comprised or consist of an infra-red emitter, a phototransistor, a voltage divider network, IC4033B and a seven-segment display unit and was mounted on the seed delivery tube. The performance of the sensor was studied for wheat, mustard and maize seeds in a test-rig developed for testing different metering mechanisms used in seed drills and planters. The test-rig comprisedmovinggrear with coated canvas belt which simulates ground speeds of a seed drill with provisions to vary the speed of operation and a universal mounting frame to accommodate various seed metering mechanisms. The sensor successfully sensed the seed droppings for mustard and wheat seeds with a maximum error of 18%. These errors were due to inability of the sensor to detect multiple seeds in a small amount of time. Errors within 10% were found for maize seeds because of more time gap between two consecutive seed droppings. The developed sensor has the potential for sensing the seed flow by which the operator can easily know the workability of the metering device.

Karayel*etal.*(2006) used a high-speed camera system for evaluating seed spacing uniformity and velocity of fall of seeds. The performance of the high-speed camera system in terms of seed spacing evaluation was compared with a sticky belt test stand, used as a reference. Identical seed planting was evaluated by applying both methods simultaneously using wheat and soybean seeds. The speed of the metering rollers of the seed drill was set at 10, 20, 30 and 40 rpm and that of the seed drill at a simulated travelling speed of 1 m/s. In general, the high-speed camera system worked well in obtaining the seed spacing and velocity of fall of seeds. In all the tests with the wheat and soybean seeds, the high-speed camera system did not miss any seed. The sowing uniformity of the seed drill as investigated was affected by the speed of the metering rollers. Coefficient of variation of seed spacing, velocity of fall and coefficient of variation of velocity of fall of seeds decreased as the speed of the metering rollers increased.

The technical feasibility of mechanical planting of sunflower seeds was studied by (Singh and Sharma, 2006). Four different rollers were fabricated and evaluated under laboratory conditions in terms of quantity of seed metered, volumetric cell fill, seed germination and seed damage at three seed column height in the hopper and four different speeds. Uniformly shaped triangular small cell type roller gave optimum performance between 17 – 40 rpm of its operation.

A prototype of single row manually operated sunflower planter by using optimum roller was developed which was evaluated at the Kurukshetra University, Haryan State in India and on farmers' fields. The average field capacity of the planter was 0.103 ha/h. The average seed germination was 22.66 plants/m^2 and 14.66 plants/m^2 for MYCO-8 and HS-1 varieties, respectively. The sowing of sunflower by planter resulted in net saving of 57.16 man-hours and 2.25 tractor-hours per hectare over dibbling method.

Celik*etal.*(2007) evaluated four different type of seeders for seed spacing, depth, uniformity and plant emergence at three forward speeds (3.6, 5.4, and 7.2 km/h). The planter types were: no-till planter, precision vacuum planter, universal planter, and semi-automatic potato planter. The sowing uniformity of the horizontal distribution of seed was described by using the multiple index, miss index, the quality of feed index and the precision in addition to the mean and standard deviation and the coefficient of variation of the sample methods. Uniformity of planting depth of seed was described using the mean, standard deviation and coefficient of variation of the sample methods. Plant emergence ratios were evaluated by mean emergence time, emergence rate index, and emergence percentage. The best speed spacing uniformity and seed emergence ratio were obtained with the no-till planter and the best seed depth uniformity was obtained with the precision vacuum planter. Forward speed significantly affected only the mean emergence time ($P< 0.05$). As forward speed increases mean emergence time decreases.

A study was conducted by Gaikwad*et al.*(2007) on vacuum simulation of seeds for sowing nursery plug trays. Sixteen combinations of different nozzle sizes and suction pressures were evaluated for simulation and seeding of these seeds in plug trays. Picking of single seed was found to be influenced most by suction pressure followed by nozzle hole size for both capsicum and potato seeds. It was observed that in order to obtain value of single index more than 90%, the optimum combination of suction pressure and nozzle hole size in the case of capsicum was 500 mm of water column (4.91 kPa) and 0.49 mm respectively and for tomato it was 400 mm of water column (3.92 k Pa) and 0.46 mm, respectively.

Sahoo and Srivastava (2008) evaluated four different types of planter metering systems on the basis of their performance parameters i.e. average spacing, quality of feed index, multiple index, miss index, degree of variation and seed damage for metering-soaked okra seed at three levels of cell size and four levels of cell speed. The average spacing observed was closed to the theoretical spacing for cell size equal to maximum seed dimension. The quality of feed index was influenced highly by metering systems, cell size and cell speed. The metering systems influenced the seed damage the most followed by cell size. It was concluded that inclined plate metering system was best suited for metering-soaked okra seed.

To compare the performance of belt type planter with pneumatic planter, ridge seeder and manual planting, Kamaraj and Kathirvel (2008) developed tractor operated prototype belt type cotton planter and evaluated its performance under actual field conditions. The belt type cotton planter recorded minimum draft of 950 N and minimum fuel consumption of 3.79 l/h. The belt type cotton planter proved its superiority by registering 73.33% of two plants per hill, 6.67% of missing hills and maintained the recommended plant population and desired plant spacing. The use of belt type cotton planter for planting cotton resulted in 68.62 and 98.46% saving in cost and time, respectively when compared to the manual planting.

Barut (2008) studied the seed coating and tillage effects on sesame stand establishment and planter performance for single seed sowing. The results showed that seed treatments had a significant effect on plant emergence date, percentage of emergence uniformity and planter performance in single seed sowing of sesame. The coating delayed seed germination, therefore the naked sesame seeds had the most rapid emergence and the maximum percentage of emergence. The precision was 16.25% to 19.19%, indicating that the planter performance was better as compared to previously published upper limit of 29%. The parameters were not affected statistically by tillage treatments. However, the precision of the planter was better on traditional plots due to proper soil and seed contact.

Bakhtiari and Loghavi (2009) studied an innovatively designed tractor mounted ground wheel driven triple unit row crop precision planter capable of planting three rows of garlic. The performance parameter measured during the field test included seeding mass rate, seeding depth, seed spacing, miss index, multiple index and seed damage. The results showed that the new machine is capable of planting 2, 20,000 plants/ha at the seeding depth and spacing of 12.3 and 22.7 cm respectively.

A two row manually operated direct seeder for onion crop using inclined plate metering mechanism was developed and evaluated in the field by Chhina (2010). The sowing of onion was done with plate having 12, 24 and 36 grooves. The required plant population was achieved with the plate having 24 grooves. The average plant height of direct sown onion after 90 days was 216.7 mm which was higher than transplanted crop (159.0 mm) whereas at harvest, the plant height of direct sown crop was comparable with the transplanted crop. The neck thickness, bulb weight and yield of transplanted onion were slightly higher than direct sown crop.

A field study to investigate the performance of an auto feed cup-belt potato planter under different operation conditions with different tuber shapes was conducted by Al-Gaadi (2011). The operation conditions considered in the study included three forward ground speeds (1.8, 2.25 and 3.0 km/h), four ratios of forward speed to feeding mechanism speeds (1.22, 1.39, 1.78 and 2.0) and two feeding gate heights (80 and 100mm). The whole and cut tubers were utilized to provide different shapes of the tubers that relatively had the same size considering the tubers longest dimensions. The performance of the planter was evaluated based on the coefficient of variation (CV), the multiple index (MULTI), the miss index (MISI), the quality of the feed index (QFI) and the precision index (PREC). The result of the study revealed that the tuber shape was statistically found to have significant effect on the CV and QFI only. For the whole and cut tubers, the CV and QFI were proportional to the cut speed; however, inversely proportional to the gate height and speed ratio.

2.6 Existing Planters in Nigeria.

Abubakar (1994) developed a manually operated multi crop (maize, cowpea and groundnut) rotary jab planter for sandy loam soils under field and laboratory evaluation. Field performance revealed slightly different result due to the effect of the soil moisture content and planting speed and the result for the mixed cropping germination count, placement depth and seed spacing were 88.0%, 3.79cm and 35.30 cm respectively. While the result obtained from the laboratory test for discharge rate and seed spacing were 24.28 kg/ha, 18.05 kg/ha, 41.01 kg/ha, 25.04 cm, 23.12 cm and 37.54 cm respectively.

Isiaka*et al.*(2000) developed a two-row animal drawn planter which uses seed metering cells that drive their power from the traction wheel through a gear arrangement. The planter was tested both in the laboratory and on the field to evaluate its performance using maize seed with a forward speed of 0.82 m/s, the result obtained for seed rate, seed damage and hill distance were 15.50 kg/ha, 0.8% and 36.55 cm respectively. The field capacity, field efficiency and average required draft to push the planter were also 0.44 ha/hr., 85% and 978N.

In the same trend, Isiaka*etal*. (2001) compared the effectiveness of the developed planter with manual planting method under ridged and flat cultivation systems. The result showed that the field capacity for double row animal drawn planter is twice the single row animal drawn planter and about eight times that of manual planting method. The plant to plant spacing and seed placement depth were more uniformly placed with the animal drawn planter than the manual planting.

Bamboye and Mofolasayo (2006) designed, fabricated and carried out performance evaluation on a manually operated two-row okra planter by conducting field and laboratory tests. The laboratory investigation included the determination of the variation in weight of seeds discharged from the two hoppers, percentage damage of seeds, and average intra-row spacing of seeds. The field tests comprised the determination of effective field capacity average depth of placement of seeds in the furrows, and mean spacing of seeds within each row. A percentage difference between the weights of seeds discharged from the two hoppers of 4.97% was obtained during testing: while the seed rate was 0.36 kg/h. A reduction in percentage damage of 3.51% was attained with spacing varying from 59 cm to 70cm, and an average depth between 8 mm and 9 mm. the overall average efficiency of the planter was recorded as 71.75%.

In the same trend, Adisa and Braide (2012) designed and constructed a template row planter to improve planting efficiency and reduce drudgery involved in manual planting method. They also recorded that the row planter increased seed planting, seed/fertilizer placement accuracies and it was made of durable and cheap material affordable for the small-scale peasant farmers. The operating adjusting and maintaining principles of the planter were made simple for effective handling by unskilled operators (farmers). The field capacity of the template row planter was found to be 0.20 ha/h. Template seed filling efficiency was found to be 88% and draft requirement was found to be 85N at average speed of 2.16 km/h

Ikechukwu*et al*. (2014) design and fabricated a manually operated single row maize planter capable of delivering seeds precisely in a straight line with uniform depth in the furrow, and with uniform spacing between the seeds. The results obtained from the trials tests showed that the planter functioned properly as expected with a field capacity of 0.0486 ha/hr. visual inspection of the seed released from the planter's metering mechanism showed no visible signs of damage to the seeds.

Odunma *et al.*(2014) developed a manually operated cowpea precision planter under laboratory and field investigation. The planter effectively metered out two seeds per discharge at an average planting depth of 2.22 cm and minimum seed damage of 2.34%, the field efficiency and capacity were 71.71% and 0.26 ha/hr. respectively.

Alhassan & Adewumi, (2018)developed a motorized self-propelled multi-crop precision planter with new metering mechanism design concept. 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 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/h. working speed with a field efficiency of 81.2%, minimal seed damage and field capacity of 0.1 ha/h.

Soyoye*etal*. (2016, and 2018) designed a manually operated vertical seed-plate maize planter with 89.7% field efficiency and 1.53 ha/hr planting capacity.

Agidi *et al.* (2017) developed A Tractors drawn Soybean drum planter. The major components of the developed planter were three drums with predetermined hole sizes at the exterior ends, a central rectangular shaft, spring soil openers, roller soil coverers, tractor hitching points, two wheels and power transmission mechanism and frame. Using three test speeds, the planter was preliminarily assessed for seed rate, soil opening, covering and germination efficiencies. Results obtained indicate that desirable seed rate values of 47.7 and 61.2 kg/ha were observed for tractor/implement speeds of 20 and 16 km/h, respectively. The highest germination efficiency of the planter was 81.3% at tractor/implement speed of 16 km/h with corresponding soil opening efficiency of 94%.

Upahi (2017) developed and carry out performance optimization on a two – row engine – propelled seed ridge planter as in plate 2.5 which has two hoppers, two seed metering units, two delivery chutes, two coulters, two soil covering devices and a drive mechanism. The evaluation of the machine was in term of planting speed, seedling emergence, plant to plant spacing, energy expended, seed delivery rate, number of seeds per hill and seed damage. The result for the seed delivery rate was 19.8 kg/ha, effective field capacity of 0.22 ha/h, field efficiency of 70.71%, average planting speed of 0.55m/s, average plant spacing of 25.9 cm and least expanded energy of 261.82 MJ/ha.

Plate 2.5: A 2-row Engine-Propelled Seed Ridge Planter (Upahi, 2017).

Saleh (2021) developed a Multi-Crop Single-Row Hand-Pushed Planter which consist of the main frame, adjustable handle, seed hopper, seed metering device, adjustable furrow opener, adjustable furrow closer, drive wheels, seed tube and ball bearings. Most of the components are produce locally. Results obtained shows the planter to be efficient on maize, soybeans and sorghum with field efficiencies of 87.10, 82.85 and 81.08% respectively.

2.7 Summary of Literature Reviewed

S/N	AUTHOURS	ITEM	PROBLEMS OBSERVED	POSSIBLE SOLUTION
1.	Abubakar (1994)	A Multi-Crop Rotary Jab Planter	Field performance shows slight difference from the laboratory test	Good field work days should be observed and also lubricate the bearing

2.	Isiaka*et al*. (2001).	Development of a 2-rows animal drawn seed planter.	The hopper of the planter was observed to be touching the ridge. Metering unit was also, observed to be over clogging with seeds.	The hopper should be raise up. Metering unit should be enclosed to avoid over clogging of seeds.
3.	Karayel*et al*. (2006).	Laboratory measurement of seed drill, seed spacing and velocity of fall of seeds using high-speed camera system.	The sowing uniformity is affected by the speed of the metering rollers.	By increasing the speed of the metering rollers.
4.	Sukhbir*et al*. (2006)	A Technical feasibility of mechanical planting of sunflower seeds.	It was observed that 2-3 seeds/hill in the field test.	The seed cells should be reduced to take only 1 seed/hill.
5.	Celik*et al*. (2007)	Effects of various planters on emergence and seed distribution uniformity of sunflower.	Forward speed affected the mean emergence time (p<005) as the forward speed increased mean emergence time decreased.	Optimum forward operating speed should be obtained.
6.	Upahi (2017)	Development and performance optimization of A two-row engine-propelled seed ridge planter	He observed that the maximum speed of the engine was not enough	Bigger engine should be used
7.	Agidi*et al*, (2017)	Design, Fabrication and Testing of a Tractor Drawn Soybean Planter	The diameter of the traction wheel (320 mm) is small making it difficult to work on the ridges There are seeds losses during turnings	The traction diameter should be increase or the planting should be done on flat land. Incorporating central seeds locking devices to prevent losses at the turnings.
8.	Elijah *et al*. (2018)	Development of a self-propelled multi-crop two rows precision planter: A new design concept for metering	At lower engine speed, a high number of seeds were discharged and percentage seeds damage was also, high	Optimum engine speed will be used to minimise the percentage seeds damage

		mechanism		
9.	Saleh (2021)	Development of a Multi-Crop Single-Row Hand-Pushing Planter	Bearings need to be lubricated often	Bearings lubricating nipples should be closed to keep the lubricant stay long enough.

2.8 Deduction from Literature Review (Research gap)

From the past work reviewed on planters the following have been observed:

1. Most of the planters are actually imported, they are not produced locally in Nigeria, and because they are imported they are beyond the rich of a small soybean farmer, and even were the planters are afforded, the spare parts are not readily available.
2. The planters are not produce from locally available materials, while there are locally available materials for planters' production at affordable price.
3. In conclusion, there is no at present a specialised locally produced soybean tractor mounted capable of planting locally grown soybean seeds capable of obtaining optimum plant density or number of plant per hectare.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

All the materials used in the design, fabrication, assembly and field works are detailed under the following headings:

3.1.1 Instrumentation used in the design

A set of personal computer, Solidworks 2018 software, (SAS software, version 9.4) software and a printer.The instruments needed for the determination of the seed properties design related include; Electric weighing balance (Model number: EK5350, Brand name: Camry, Capacity: 5 kg, 0.01 g). Digital vernier caliper (Siemens s1m-km-225, with 0.01 mm precision), electrodes (gauge 12), stop watch (infinix hot 6 android), steel measuring tape (1 meter and 15-meter tape), welding machine (BX1-500-1, 2OON, 380V, a.c arc welding machine), lathe machine (SN 40 B, EX-12), filing machine (professional 335), drilling machine (table drilling machine: BOKY, Capacity: 360rpm, Model: 23R22), tractor (EICHER 5660 Model, 50hp), Heating Drying Oven (Model: DHG XMTD-8222).

3.1.2 Selection of materials for construction

The materials were selected based on their strength, availability, durability, and cost effectiveness. These materials include: angle iron of 60 mm x 60 mm of mild steel, 2 mm mild steel sheet metal, 5 mm x 50 mm flat bar, 25 mm diameter mild steel bar, 25 mm diameter bearing, 15 mm x 196 mm aluminum disc, 17 and 22 bolts and nuts.

3.2 Design Consideration

The Four-Row Tractor Mounted Soybean Planter was designed and constructed by considering the following factors;

i. Rigidity of the machine to withstand the various working stresses in the field.

ii. Accurate and uniform placement of seeds in an acceptable distribution pattern and desired depth with minimum damage.

3.3 Determination of Seed Properties Related to Design of Soybean Planter

Two major varieties of soybean commonly grown in the North-western part of Nigeria wereobtained from Seed Production Unit, Institute for Agricultural Research (IAR), Ahmadu Bello University Zaria (ABU), Nigeriafor the experiment. 1000 grain of each variety was randomly picked for the determination of size, coefficient of friction, angle of repose as prescribed by FAO, (1994). These wasachieved using the procedure outlined as follows;

3.3.1 Determination of seed sizes

The length, width and thickness of the soybean seed was determined by measurement using digital Vernier caliper as shown in Appendix A. A 100 samples were selected randomly from the bulk of 1000 soybean grain.

3.3.2 Determination of seed angle of repose

A funnel with a wide outlet is fixed at a distance of 100 mm above flat surface where a piece of paper is placed on the surface. The soybean seed samples collected in a separate container was then poured gradually in the funnel allowing the content to flow through and accumulate on the paper placed on the flat surface to form a conical heap. The height and diameter of the heap was measured, and the procedure was repeated three times and the angle of repose was calculated as shown in Equation 3.1

$\theta = \tan^{-1}\frac{(2H)}{D}$ − − − − − − − − − − − − − − − − 3.1(Maduako and Hannan,2004),

Where; $\theta =$ angle of repose (°)

$H =$ height of the heap (mm)

$D =$ Diameter of the heap (mm)

3.3.3 Determination of seed coefficient of friction

The coefficient of friction of the seed was determined on plywood and 2 mm mild steel metal surface using a tilting table. The seed samples were poured on the square flat material (plywood and 2 mm mild steel metal) one after the other, the material is then tilted from one side, as soon as the seed samples on the surface of the material begin to slide down, the angle of inclination of the soybean 'α 'is then measured. This is in line with the procedure adopted by Maduako and Hannan (2004). Coefficient of friction is determined using Equation 3.2

$\mu = \tan\alpha$ − 3.2 Maduako and Hannan (2004)

Where; � = coefficient of friction (unit less)

$\alpha =$ angle of inclination of the table to the horizontal (°)

3.4 Design of component parts

The planter comprises the following components; hopper, frame, metering mechanism, furrow opener, delivery tube, furrow cover, traction/press wheel. The detailed design of each component parts of the planter are presented as follows;

3.4.1 Hopper

The hopper was made from a mild steel metal plate of 2 mmowing to it availability and strength forming a hollow frustum of a triangular prism as suggested by Soyoye*et al*. (2016) with a bottom base of 60 mm X 40 mmand a top area of 230 mm X200 mm, the height is 250 mm. The hopper was designed with the consideration of the soybean grain's angle of repose 27°. It has a slant base to enable soybeans seeds flow down and pass through the outlet. The hopper is to contained soybean seeds and is covered to prevent soybeans seed from jumping out and also, to protect the seeds from rain droplet in case it's raining during field operation. The cover is made from 2 mm mild steel plate of 230 mm X 200 mm X 5 mm. The hopper details design is shown in Appendix: A in Figure A9.

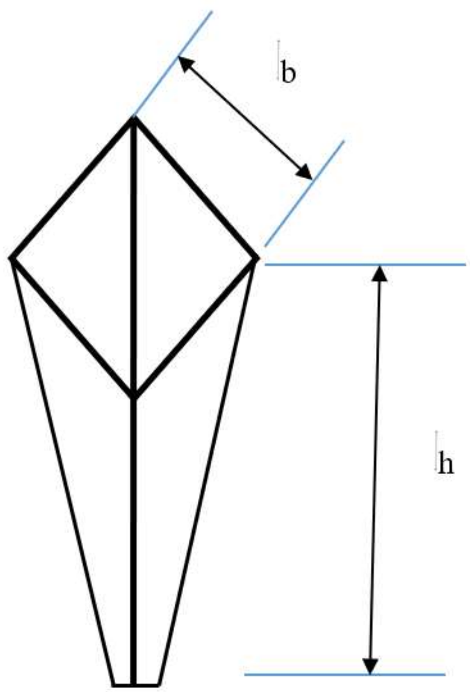


Figure. 3.1 The hopper configuration

3.4.2 Hopper capacity

Is the amount of seeds or quantity of seeds the hopper can bear, based on Soyoye*et al*.(2016)Thecapacity of the hopper is expressed as shown in Equation 3.3

$$Hc = \frac{TVH}{AVS} - 3.3$$

Where;

$$\text{Hc} = \text{The hopper capacity } (\text{cm}^3)$$

$$\text{TVH} = \text{total volume of the hopper } (\text{cm}^3)$$

$$\text{AVS} = \text{average volume of seed} (\text{cm}^3)$$

$\pi = 3.142$

$$\text{TVH} = 0.00365 \text{ m}^3$$

The volume of an average grain was also determined using the Equation given by (Jain and Bal., 1997) as shown in Equation 3.4;

$$AVS = 0.25 \left\{ \left(\frac{\pi}{6} \right) L(W + T)^2 \right\} - - - - - - - - - - - - - - - - 3.4$$

Where;

$$\text{L} = \text{length of the grain, 7.81 (mm)}$$

$$\text{W} = \text{width or breadth of the grain, 3.51 (mm)}$$

$$\text{T} = \text{grain's thickness, 6.51 (mm)}$$

$$\text{AVS} = \text{average volume of grain } (mm^3)$$

$$\text{AVS} = 103.916736 \, mm^3$$

3.4.3Metering mechanism

The metering mechanism was made of aluminum disc; the disc was enclosed with a circular flat bar casing with a gap of 2 mm. The hole is expected to pick only one seed when it rotates in a vertical plane at the bottom of the hopper. It was mounted on a horizontal shaft which is driven directly by the side traction wheel. The metering mechanism of the developed planter is shown in Appendix: A, Figure 8.

3.4.4Number of cells on the metering mechanism

The number of cells were determined using the expression in Equation 3.5 (Ibukun*etal.*,2014).

$$Number\ of\ Cells = \frac{\pi d_w}{S_c} ---------------------- 3.5$$

Where;

d_w = diameter of the planter ground wheel (mm)

S_c = intra row spacing of the seed (mm)

$\pi = 3.142$

The traction wheel (motorcycle rear tyre) diameter of 540 mm and intra-row spacing of 50 mm were used. Therefore, the number of cells on the metering mechanism was 47 holes.

3.4.5 Furrow opener

Furrow openers open the soil where seeds metered out and falling through the delivery tube are dropped into the soil and covered. The furrow opener in this design was the adjustable knife-like type formed from sheet metal of 5 mm thickness containing an angle iron of size 60 mm x 60 mm welded behind forming a 'v' shape to enable easy cutting through the soil cuts and pushing the soil sideways to form a furrow according to Murray *et al* .(2006). The adjustable furrow opener as shown in Figure 3.2 permits planting for each variety's ideal ground depth requirement, 17 Nuts and bolts was used to fasten the device to the frame through a hole drilled on the frame.Bosoi*et al*. (1988) proposed the furrow soil opener for crop propagation. The runner boot has the following configurations as extracted from ASAE (2005): width of cut, w = 53mm, Angle of penetration, $\alpha = 51^o$

Figure. 3.2 The furrow opener configuration.

3.4.6Delivery tube

This is a tube through which the soybeans seeds are metered out by the holes on the metering mechanism disc travel before they are deposited into the furrow. The seed delivery tube is located below the metering mechanism casing into which the metering plate releases the seed after picking the seeds from the bottom of the hopper.

3.4.7Planter frame

This is a bar on which the four-row planter unit were mounted and also adjustable for planting spacing. The individual planter units were attached to the bar with a U-bolt through a connecting frame, as shown in Appendix: A, Figure 4.

3.4.8 Traction Wheel

Motorcycles rear tyres were used as the traction wheel which are located at the right side of the frame (individual planter unit). The traction wheel was designed to drive/rotate the metering mechanism as its rotate via a shaft which collect the soybeans seed and deliver them to the opened soil, as shown in Appendix: A, Figure 6.

3.5Determination of seed population

The seed population was determined by using Equation 3.6 (Soyoye*et* al., 2016)

$$P_s = n\left[\frac{A}{S_r S_c}\right] ---------------------- 3.6$$

Where;

P_s = actual number of seeds discharged

n = average number of seed discharge per hole

A = area of the field (m^2)

S_r = inter – row spacing (cm)

S_c = intra – row spacing (cm)

With $n = 1$ seed, $A = 3 \text{ X } 8$ m, $S_r = 0.5$ m, $S_c = 0.05$ m, then $P_s = 960$ seeds.

3.5.1 Planter unit spacing

The developed four-row tractor mounted soybeans planter has four individual units/components which atinter-row spacing(50 cm) as recommended by IITA (2020) on the best agronomic practices of planting soybeans.

3.5.2Planter capacity

The capacity of the planter in termsof seeds quantity planted per time was obtained from Equation 3.7 by

(FAO, 1994):

$$CPN = \frac{V_p}{S_c} \times N_s ----------------- 3.7$$

Where;

$$N_s = number\ of\ seed/hole$$

$$CPN = capacity\ of\ the\ planter\ in\ terms\ of\ seeds\ planted\ per\ time.$$

$V_p = speed\ of\ the\ planter\ (km/h)$

$S_c = intra - row\ spacing\ (cm)$

When the planter drops 1 seed at intra row spacing of 5 cm and at the same speed

CPN = 12 seeds / s

3.6 Establishment of Design Parameters

Details of the design parameters are shown in Appendix D

3.6.1 Weight of the planter

Weight of the planter component acting on the wheel are shown in Equation 3.8

$$= W_m + W_h + W_{fr} + W_c ------------------ 3.8$$ (Khurmi and Gubta, 2005)

Where;

Wm = Weight of the metering plate (2.0 kg)

Wh = Weight of the hopper (1.68 kg)

$\text{Wfr} \cdot = \text{ Weight of the frame (7.85 kg)}$

$$\text{Wc} = \text{Weight of the metering casing (1.74 kg)}$$

Then the weight of a single planter was computed as 13.27 kg. For the four-row planter, the net weight is 53.08 kg.

3.6.2 Total torque

The was calculated using Equation 3.10

$$\text{T} = H_m \times r_w ---------------------- 3.9$$

$$H_m = \text{CA} + \text{Wtan}\phi ---------------------- 3.10 \text{(Muhammad, 2010)}$$

Where;

$\text{H}_\text{m} = \text{Maximum thrust (kN)}$

$\text{r}_\text{w} = \text{Radius of the traction wheel (0.37005 m)}$

$\text{C} = \text{Soil cohesion, 13.5 kPa for sandy soil (Smith and Smith, 1988)}$

$\phi = \text{Soil frictional resistance, } 0 - 20° \text{ for non} - \text{clay soil}$

$\text{W} = \text{Weight of the planter (kg)}$

3.6.3Determination of the shaft diameter

The shaft size was determined using Equation 3.11 (Hall *etal*, 1980) as;

$$d^3 = \frac{16}{\pi\tau_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} ------------------3.11$$

Where;

$\text{d} = \text{shaft diameter(mm)}$

$(K_b \ and \ K_t)$ = Combine shocks and fatigue factors applied to bending and torsional moment respectively.

$(M_b \ and \ M_t)$. = bending and torsional moment $(Nm \quad)$
$\boldsymbol{\tau_s} =$ allowable stress of the steel shaft (N/m^3)

Allowable shear stress for shaft without keyways, $\tau_s =$ least value of 0.3 yield strength and 0.18 ultimate strength of the shaft material (Kurmi and Gupta, 2005)

The material selected for the shaft is mild steel (C 1040) with ultimate and yield strength of 770 and 580 MN/m^2 respectively(Kurmi and Gupta, 2005)

$0.3(580) = 174 \text{ MN}/m^2$

$0.18(770) = 138.6\text{MN}/m^2$

The smaller value is 138.6 MN/m^2 and further reduced by 25 due to the presence of key way

Allowable shear stress for shaft, $\tau_s =$ 34.65 *MN/m^2*

$K_b = 1.5 \ to \ 2.0$ and$K_t = 1.0 \ to 1.5$(Kurmi and Gupta ,2005)

Table 3.1 Summary of design calculation

S/N	COMPONENTS	EQUATION	RESULTS
1.	Hopper capacity	$Hc = \frac{TVH}{AVS}$	$11.104 \ kg$
2.	Determination of Number of Cells in the seed metering device	$N = \frac{\pi dw}{Sc}$	47
3.	Seed delivery Rate	$R_s = \frac{Qp}{A}$	$48.2 \ kg/ha$
5.	Determination of the shaft diameter	$d^3 = \frac{16}{\pi\tau_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2}$	$d = 25 \ mm$

3.7 Fabrication and Assembling of the Planter

The 2 mm sheet metal was cut with angle grinder machine according to the design of the hopper size and welded with (gauge 12) electrode using electric welding machine. Angle iron was marked, cut and welded together to form the frame of the planter. Aluminum disc was machined according to the specifications of the designed metering mechanism with lathe machine and the cost of fabrication of the developed planter are shown in Table 3.2. The component parts of the Four-Row Tractor Mounted Soybean Planter were assembled using assorted bolts and nuts to form a functional unit of aplanter in the Department of Agricultural and Bio-Resources Engineering workshop, Faculty of Engineering, Ahmadu Bello University, Zaria Nigeria as shown in plate 4.1

3.8Performance Evaluation of the Machine

The performance evaluation of the developed planter includes both laboratory and field tests. The procedures prescribed by (FAO, 1994) on testing and evaluation of agricultural machinery and equipment was adopted; the laboratory test includes seed delivery rate, R (kg/ha), Percentage Seed Damage (%), and Spacing Evenness (cm). The field test includes; Field Efficiency (%), field Capacity (ha/h), Germination Count (%), and Planting Depth (cm). Number of seed dropped per hole was determined at both in the laboratory and on the field. These were achieved using the following expressions:

3.8.1 Seed delivery rate R (kg/ha)

The seed delivery rate was determined from the formula Equation 3.12 as reported by (FAO,1994)

$$R_s = \frac{Q_p}{A} ----------------- 3.12$$

Where;

R_s = Seed delivery rate (Kg/ha)

Q_p = Quantity of planted seed (kg)

A = Area of planted field (ha)

3.8.2 Percentage seed damage, Ds (%)

The percentage seed damage was determined from the Equation 3.13 as reported by (FAO, 1994);

$$D_s = \frac{Q_d}{Q_p} \times 100 - - - - - - - - - - - - - - - 3.13$$

Where;

Q_s = Quantity of seed damage (%)

Q_d = Quantity of damaged seed per unit time (kg)

Q_p = Quantity of planted seed per unit time (kg)

3.8.3 Seed spacing evenness,Eu(cm)

The spacing evenness was calculated from Equation 3.14 by (FAO, 1994)

$$E_\mu = \frac{E - SSD}{E} - - - - - - - - - - - - - - - - 3.14$$

Where;

E_μ = *Spacing evenness*

E = *Average seed spacing (cm)*

$SSD = Seed\ spacing\ Standard\ Deviation$

3.9.4 Number of Seed PerHole, En

$$E_n = \frac{N - NSD}{N} \text{ ---------------- } 3.15$$

Where; E_n = Number of seed per hole evenness

N = Average number of seed

NSD = Number of seed standard deviation.

3.10. Laboratory Evaluations

The following laboratory evaluations were carried out on the developed soybean planter

3.10.1 Laboratory evaluation instruments

Electric weighing balance, developed planter, tractor(EICHER, Model: 5660, 50 hp), marker, Vanier caliper and measuring tape and stop watch.

3.10.2 Laboratory evaluation materials

Soybean (TGX1951-3F) variety, containers,

3.10.3 Percentage seed damage

This experiment was done in three sets: with the hoppers filled up, half-filled and one quarter filled. For each case, the planter was mounted to the tractor and allowed to complete over five revolutions of the wheel. At the end, the broken seeds and whole seeds metered were collected and weighed and computed using Equation 3.16(FAO, 1994)as showing in Table 4.1.

$$\text{percentage seed damage} = \frac{\text{Weight of broken seeds}}{\text{Weight of whole seeds} + \text{Weight of broken seeds}} --- 3.16$$

3.10.4 Determination of seed delivery rate

This test was done in three stages for the developed planter. The first was with the hoppers at capacity, the second was with the hoppers half-filled and the third was with the hoppers quarter-filled. At each stage, the planter was allowed to complete five revolutions of the wheel. The dropped seeds were then collected and weighed. Each stage was repeated thrice and the average values were obtained. Seed delivery rate was determined from Equation 3.17(FAO, 1994)

$$R_s = \frac{Q_p}{A} ----------------------3.17$$

Where;

Rs = Seed delivery rate (kg/ha)

Qp = Quantity of planted seed (kg)

A = Area of planted field (ha)

3.11. Field Performance of the Planter

The developed planter was evaluated on the field after the satisfactory laboratory evaluation.

3.11.1 Field performance evaluation equipment

The developed planter, tractor (EICHER, Model: 5660, 50 hp), measuring tape, soil core sampler, stop watch, note pad.

3.11.2 Field performance evaluation materials

Soybean (TGX1951-3F) variety, pecks,

3.11.3 Field evaluation of the planter

The developed Four-Row Soybean Planter was mounted on the tractor's three-point linkage at the rear of the tractor (EICHER, Model: 5660, 50hp) and was taken to the field, (Agricultural and Bio-Resources Engineering Department's Experimental plot). The tractor was set to three (3) different speeds level S1 =7 km/h, S2 = 10 km/h and S3 = 15 km/h and set to two(2) different depth level of planting D1 = 2 cm and D2 = 4 cm, which is within the range of the recommended depth of planting soybean byIITA (2020). The experimental plot's soil samples were taken at 20 cm depth using the soil core(25 cm) sampler and taken to the oven (Heating drying oven, Model: DHG 105°C) in the laboratory to determine the soil moisture content. The experimental field was 16x9 m replicated on three (3) different plots.

Plate 4.1Developed Planter Mounted on the Tractor during planting operation

The following parameters were obtained from the field after evaluating the planter:

3.11.5 Field efficiency ε, (%)

The field efficiency was calculated from the Equation 3.19 as reported by FAO (1994)

$$\varepsilon = \frac{2{,}778\ \mathrm{M}}{\mathrm{TWS}} ------------------- 3.19$$

Where;

$\varepsilon =$ Field efficiency (%)

M = Plot size completed (m^2)

T = Total time to complete area M (h)

W = Working width(cm)

S = Working speed (m/s)

3.11.6 Effective field capacity,EFC(ha/h.)

The effective field capacity was determined from Equation 3.20 as reported by FAO (1994)

$$A = \frac{M}{(10{,}000T)} ------------------ 3.20$$

Where;

M = Plot size completed (m^2)

T = Total time to complete area M (h)

A = effective field capacity (ha/h)

3.11.7Germination Count, C_g (%)

The germination count was obtained from Equation 3.21 as reported by FAO (1994)

$$C_g = \frac{S_g}{s} ------------------------- 3.21$$

Where;

S_g = Germinated seed

S = Total seed planted

C_g = Germination count.

3.11.8Seed Depth Evenness, Ed (cm)

The seed depth evenness was determined from Equation 3.22as reported by FAO (1994);

$$E_d = \frac{D - DSD}{D} ---------------------- 3.22$$

Where;

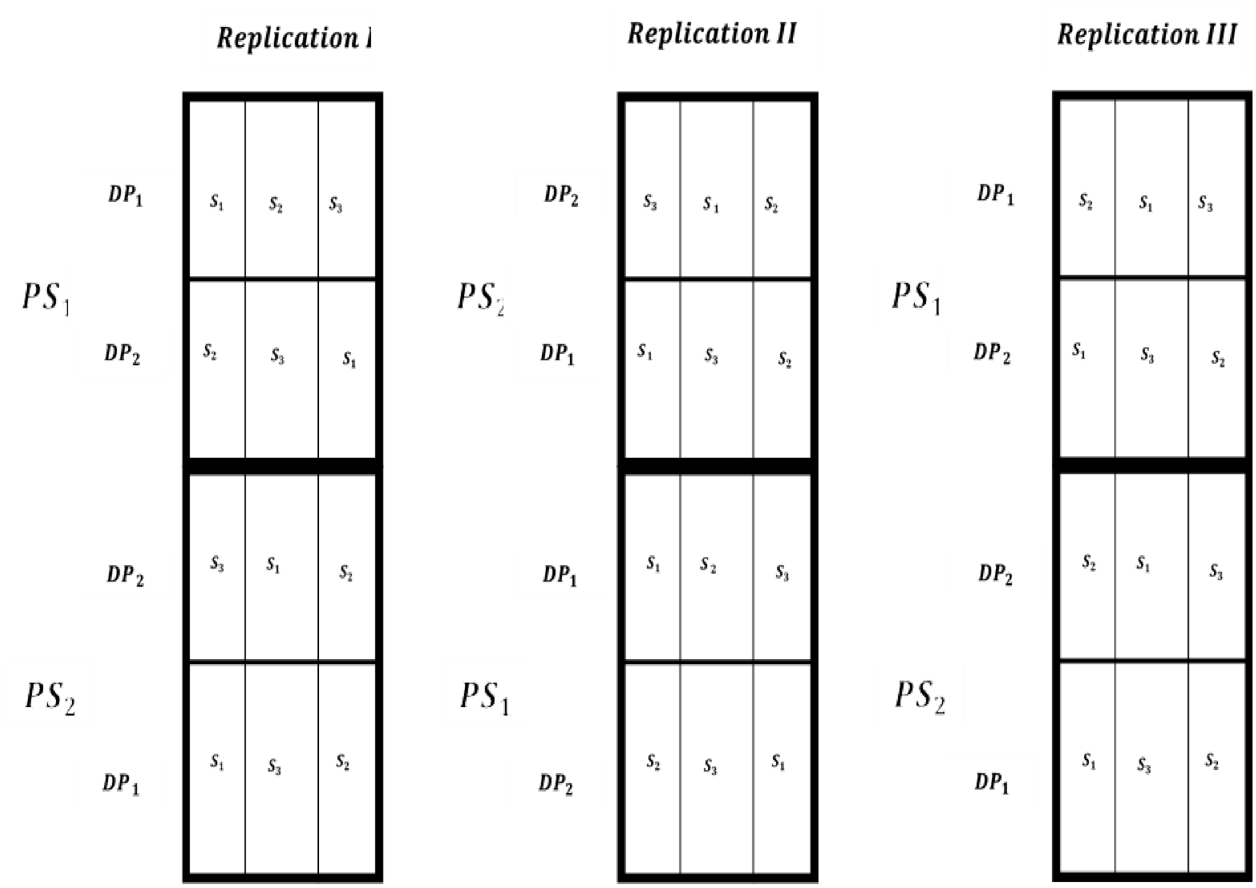
D = Average depth (cm)

DSD = Depth standard deviation

E_d = Seed depth evenness

3.12 Experimental Design and Analysis

The experimental design was based on Randomized Complete Block Design (RCBD). Three levels of working Speed (S1, S2, S3), two levels of planting depth (DP1, DP2) with three replications were considered for the variety of soybean selected. Analysis of variance (ANOVA) andfurther test were computed using Duncan multiple range to see level of significance mean differences of the effects of the variables, their interaction, and to determine the most appropriate working speed among the selected speeds. The layout of experimental design and the outline of the (ANOVA) are shown in figure 3.3and in Table3.2 respectively.



Planting depth= DP , and planting speed= S.

Figure 3.3: Layout of Randomized complete block design

Table 3.2: Analysis of Variance (ANOVA) table for aRandomized Complete Block Design(RCBD)

Source of Variation	df	*SS*	*MS*	*F-Value*	*P-Value*
$Replicate$	$3-1=2$				
$\boldsymbol{Whole\ plot.\ \ Planting\ depth}\ (\boldsymbol{DP})$					
DP	$2-1=1$				
$Error(DP) = Rep \times DP$	$(3-1)(2-1)=2$				
$\boldsymbol{Sub\ plot.Planting\ Speed}(\boldsymbol{S})$					
DP	2				
	$3-1=2$				
$DP \times S$	$(2-1)(3-1)= \ 2$				
$Error\ (S)\ =\ Rep \times S(DP)$	$2(3-1)(3-1)=8$				
Total	$3 \times 2 \times 3 - 1 = 17$				

Table 3.3: Bill of Engineering Materials and Evaluation of the Tractor Mounted Four-Row Soybean Planter

S/N	**Description**	**Qty**	**Unit cost(₦)**	**Total cost(₦)**
1	2mmx1300mmx2440mm mild steel sheet	2	25,000	50,000
2	Quarter rod 10 mm x 2400 mm	1	1,000	1,000
3	Bearing P205	8	5,000	40,000
4	Dia. 50 mm x 2440 mm pipe solid	1	10,000	10,000
5	6mmx60mmx2440mm angle iron A (main frame)	4	12,000	48,000
6	6mmx45mmx2440mm angle iron B	4	6,000	24,000
7	Hinge pin for lower arm linkage	2	5,000	10,000
8	Flat bar 5 mmx2440 mm	2	8,000	16,000
9	Motor cycle tire 30017 (rear tyre) for traction wheel	4	4,500	18,000
10	Motor cycle tire rim (rear tyre)	4	12,000	48,000
11	Motor cycle tire shaft	4	500	2,000
12	Depth control wheel	2	10,000	20,000
13	Bolts and nuts Assorted	50	150	7,500
14	Washer Assorted	50	100	5,000
15	Electrode gauge 12	2 packs	3,200	6,400
16	Paints (Glossy)	1 gallon	6,000	6,000
17	Brush	4	250	1,000
18	Cutting disc flex	4	1,000	4,000
19	Filing disc flex	2	1,000	2,000
20	Thinner	4	1,000	4,000
21	Return Springs	18	2,000	36,000
22	Fabrication of 200 mm diameter x12mm aluminum seed metering disc	4	12,000	48,000
23	Pressing wheel	4	8,000	32,000
24	Standard drill bit (assorted)	10	1,000	10,000
25	Transportation		5,000	5,000
	Sub-total			453,900
26	Labour	5%	22,695	476,595
26	Miscellaneous	5%	22,695	22,695
	Grand total			**(₦) 499,290**

The total amounts to four hundred and ninety-nine thousand, two hundred and ninety naira only. Market survey conducted at Zaria and Samaru Markets, Kaduna State, Nigeria April, 2021.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1Description of the Developed Four-Row Tractor Mounted Soybean Planter

The developed Four-Row Tractor Mounted Soybeans Planter was fabricated and assembled at the Department of Agricultural and Bio-Resources Engineering Workshop, Ahmadu Bello University, Zaria. The planter comprises four individual planting units attached to the main frame (at inter row spacing of 50 cm as recommended by IITA (2020) on the best agronomic practices of planting soybeans) which have the three-point attachment to tractor rear end. Each planter unit has a hopper (mild steel plate of 2 mm), furrow opener, metering mechanism (aluminium disc), delivery pipe (rubber hose), frame (60 mm X 60 mm X 5 mm angle iron), motorcycles rear tyre (traction wheel), 2 bearings (205 mm), shaft (mild steel), 4 number of 17 bolts and nuts, and brush.

The developedfour-row tractor mounted soybean planter is shown in plate 4.2 and the results of its evaluation both in the laboratory and on the field are presented and discussed under the following sub-headings:

i. The Developed Four-Row Tractor Mounted Soybean Planter and its principles of operation

ii. Laboratory evaluation of the developed planter

iii. Field evaluation of the developed planter.

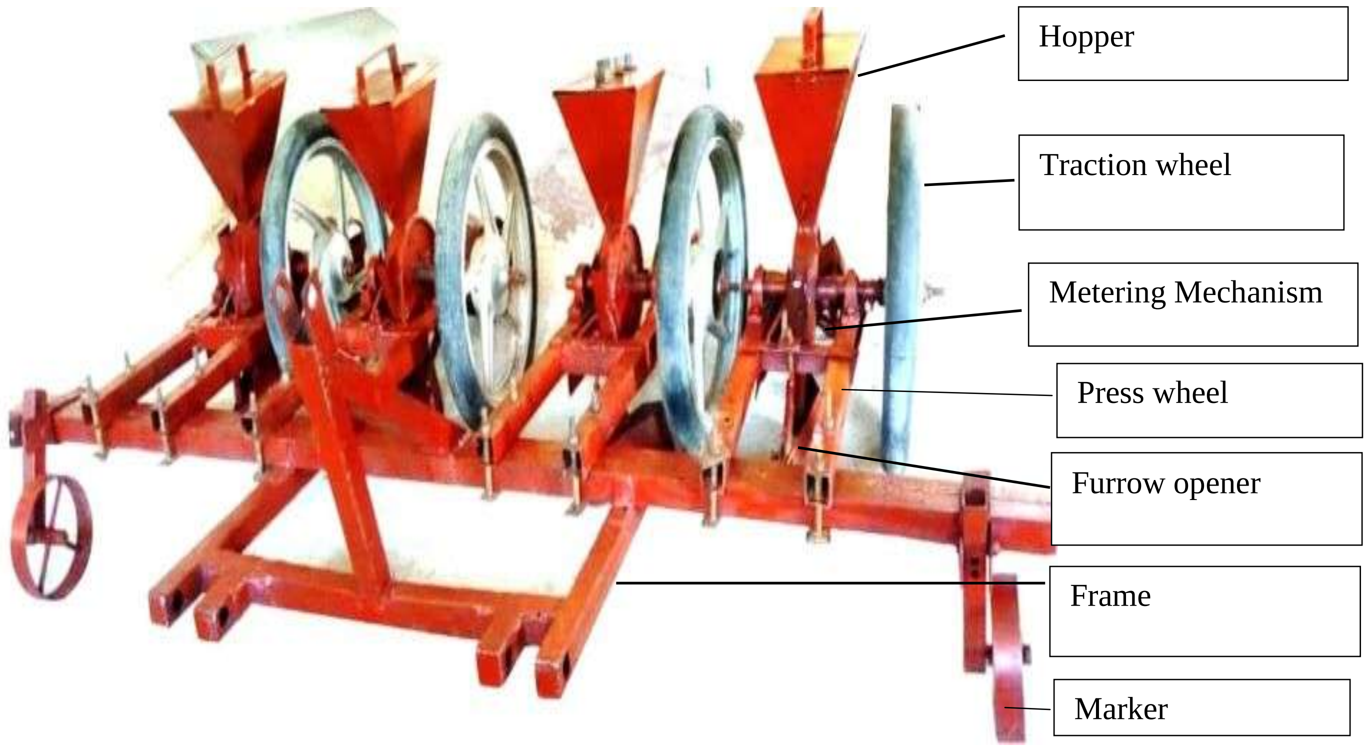


Plate 4.2: Developed Four-Row Tractor Mounted Soybean Planter

4.2.1Operation of the Developed Planter

The developed four-row tractor mounted soybeans planter has a total span/width of planting of 1.5 m of the four-rows. The planter was hitched to a 50 hpEicher 5660 tractor with the aid of the tractor three-point linkage as shown in Plate 4.2.The depth of penetration of the furrow opener in to the soil was controlled by the hydraulic control liver. Viable and sorted soybeans seeds were then poured in to the hoppers which were refilled whenever the level of the seeds gets to about one eighth of the hoppers volume.

The developed Four-Row Tractor Mounted Soybean Planter mounted on the tractor and tested in the field for its capacities, and seed germination using 9 X 16 m experimental plot replicated three (3) times on a flat land harrowed properly at the Department of Agricultural and Bio-Resources Engineering experimental plot, Ahmadu Bello University, Zaria, Kaduna State Nigeria on 20 August, 2021 raining season. From a desired starting point, the planter was lowered and adjusted to a depth of 2 and 4 cm which are among the recommended depth range of planting soybeans(2 – 4 cm) with the aid of upper and two lower links of the tractor. The tractor was then pulled along at three (3) different speeds, 7, 10 and 15 km/h to open the soil, drop the seeds and cover the seeds with the soil. The seeds were left to germinate in the field and the germination rate was assessed. Plate 4.3 and 4.4 shows acomparison of the soybean plants emerge on the field with the developed planter and conventional planter.

4.2Laboratory EvaluationsResults

The laboratory evaluation of the developed planter includes:

i. Determination of percentage seed damage
ii. Determination of seed delivery rate
iii. Determination of evenness of spacing

4.2.1 Results for Percentage Seeds Damage

Table 4.1(Appendix C) shows that the percentage seed damage of the developed planter during the laboratory evaluation is very minimal as 1.4%, which means that the developed planter is good for planting operation. This implies that the planter is mechanically efficient in the delivery of whole seeds to the soil, it shows that the developed planter has less seed damage than what Odunma*et al.*(2014), obtained 2.34%, Olajide and Manuwa (2014) obtained 2.5% and Bomgboye and Mofolasayo(2006) of 3.51%. Broken seeds reduce the number of seedlings that can emerge on a planted field. The higher the number of damaged seeds, the lower the plant population on the planted area. The developed planter has the capability of maintaining maximum plant emergence after planting in the field.

4.2.2 Results for seed delivery rate, Q

Table 4.2 shows the results of the seed delivery rate, Q of the developed soybean planter.

Table 4.2: Seed delivery rate, Q (kg/ha)

Mass of seed in 5 rev. (g)	Length of run (m)	Working width (m)	Area covered in 1 pass (sq.m)	Mass in (kg)	Area (ha)	Seed delivery rate, Q (kg/ha)	Average, Q (kg/ha)
2776	16	1.5	144	2.776	0.0144	48.2	48.2

From table 4.2 shows that the developed planter has the capacity to plant 48.2kg of soybean variety (TGX 1951-3F) per hectare of land. This figure falls within the range of seed rate specified for soybean at 5cm plant spacing and delivering 1 seeds per hole as recommended by IITA (2000). The 48.2 kg/ha at 15 km/h is similar to what Agidi*et al.* (2017) obtained as 47.7 kg/ha which is closed to the recommended quantity per hectare.

4.2.3 Results of evenness of spacing

Table 4.3 shows the results of evenness of spacing of the developed planter

Average seed spacing (cm)	Standard deviation	Evenness of spacing
5.7	2.4	0.578

Using Equation 3.14 by FAO (1994).The evenness of spacingwas determined to be 0.578. Seeding specialists and agronomists have long used 2-related statistics, average plant spacing evenness and standard deviation (SD), as the preferred metrics to quantify metric performance and plant spacing uniformity.

4.3. Field Evaluation Results

the Field Evaluation of the developed planter include:

i. Field efficiency
ii. Effective field capacity
iii. Germination count: Analysis of variance (ANOVA) for soybean emergence

The developed four-row tractor mounted soybean planter was tested in the Agricultural and Bio-Resources Engineering Department of Ahmadu Bello University, Zaria, Nigeria Demonstration plot and are shown in Plate 4.3 and a comparison with other conventional planter in plate 4.4 and discussed as follows:

Plate 4.3 Soybean planted with the Developed Planter arranged in 50 cm inter row and average 5.7 cm intra-row spacing

Plate 4.5 Soybean plants planted with a conventional planter at 60 cm inter-row spacing and averages 20 to 30 cm intra-row spacing.

4.3.1 Field Efficiency and Effective Field Capacity

Using Equation 3.19 and 3.20 as reported by FAO (1994)

Table 4.4: shows the Field Efficiency and Effective Field Capacity of the developed planter.

Distance covered (m)	Width (m)	Area covered (ha)	Effective time (s)	Total time (s)	Speed (km/h)	Field Efficiency(%)	Effective Field Capacity (ha/h)
16	1.5	0.0144	24	31.8	15	76.6	1.14

From table 4.4 the average field efficiency and effective field capacity was calculated to be 76.6 % and 1.14 ha/h of the developed planter respectively.

4.3.2Analysis of variance results for soybean emergence in the field

The number of soybean seeds that emerged in the experimental plot carried-out on the Agricultural and Bio-Resources Engineering Departments were counted and recorded from day 1 to 5 of its emergence and analyzed as follows:

Table: 4.5 Analysis of variance (ANOVA) for soybeans emergence

Source of Variation	df	SS	MS	**F Value**	**Pr > F**
Block stratum	2	352452.	176226.		
Block .Depth stratum					
Depth	1	1159765.	1159765.	336.05	0.003
Residual	2	6902.	3451.	0.04	
Depth x Speed stratum					
Speed	2	2182406.	1091203.	12.79	0.003
Depth x Speed	2	935041.	467520.	5.48	0.032

Residual	8	682684.	85336.
Total	17	5319250.	

From the Table 4.5 it couldbe seen that there is a significant difference in the depth of planting, speed as well as the interaction between the depth and forward speed of the tractor.

4.3.3Effect of planting depth on emergence of soybeans

From the results obtained on the field,it can be shown that the depth of planting has a significant difference in the emergence of the planted soybean. At 2 cm depth of planting has the highest number of plants emergence than at 4 cmas shown in Table 4.6which is similar to what Odunma*et al*. (2014) obtained at 2.22 cm. This might likely be because the soil cover in 2 cm depth is less or small, the soybean has enough energy and can easily penetrate an emerge, while in the 4 cm depth the soil is thicker, so soybean used most of its energy trying to penetrate the soil cover as a results the emergence is delay and some soybean cannot be able to penetrate and subsequently died. From Figure 4.1, it couldbe seen that at 2 cm depth have about 3754 plants emerged while at 4 cm depth about 3066.33 plants emerged. This implies that the developed planter can best be used to plant soybean at 2 cm.

Table:4.6 Effect of planting depth on emergence of soybeans

Planting Depth (cm)	Soybean emergence (%)
2	3574a
4	3066b

Means that do not share a common or same alphabet letter are significantly different on the ranking.

4.3.4 Effect of planting speed on emergence of soybeans

The data in Table 4.5, after the analyses shows that the tractor forward speed has a significant difference on the soybean emergence. From Table 4.7, it could be seen that at tractor forward speed of 15 km/h gives the best planting tractor forward speed which is similar with Agidi*et al*.(2017) which says 16km/h is the optimum soybean tractor forward speed of planting then followed by 10 km/hwhile 7 km/h gives the least soybean seedlings emergence, therefore, 15 km/h is the optimum tractor forward speed of planting with the developed planter. This is in agreement with findings of Alhassan and Adewumi (2018), who reported that the speed of operation has an effect on the performance indices of the planter.

Table:4.7 Effect of Planting Speed on emergence of soybeans

Speed (km/hr)	Emergence (%)
15	3680.5a
10	3430.7a
7	2849.3b

Means that do not share a common or same alphabet letter are significantly different on the ranking.

4.3.4 Effect of Planting Depth and Planting Speed on emergence of soybeans

Theinteractions between planting depth and speed of operation has significant effects on the soybean emergence. From Table 4.8, it couldbe see that a combination of 15 km/h at 2 cm depth of planting gives the highest number of plant emerge recording 4086.67 plants, followed by 10 km/hr at 2 cm depth of planting gives 3854.33 plants emerge, which is also reported by Agidi*et al* (2017)While at 7 km/hr gives the least plants emergence. Therefore, a combination of 15 km/h at 2 cm depth is the best combination of planting soybean with the developed planter, followed by 10 km/h at 2 cm planting depth.

Table:4.8 Effect of Planting Depth and Planting Speed on emergence of soybean

Speed of plantingkm/hr	Depth of Planting (cm)	
	2	4
7	2781c	2917.667c
10	3854.333ab	3007c

15	4086.667a	3274.333bc

Means that do not share a common or same alphabet letter are significantly different on the ranking.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATION

5.1 Summary

The research titled "Development and Performance Evaluation of a Four-Row Tractor Mounted Soybean Planter" was designed with the aid of Solidworks 2018 and fabricated on the Department of Agricultural and Bio-Resources Engineering, workshop with the used of locally available materials and was tested with the most commonly grown soybean variety (TGX 1951-3F). The test was carried out on theDepartment of Agricultural and Bio-Resources Engineering demonstration plot, Faculty of Engineering, Ahmadu Bello University, Zaria Nigeria. The research work includes design analysis, fabrication and evaluation of the planter both in the laboratory and on the field.The developed planter has functional unit offour hoppers, four seed metering units, four delivery chutes, four furrow openers, four traction wheel and four soil covering devices, the components of the designed planter were fabricated and assembled in to a functional unit.The individual planting unit are arranged on the main frame at inter row spacing(50 cm) as recommended by the agronomic practices of planting soybeans.

The developed planter was evaluated during 2021 raining season on the Department Experimental Field using 3x2 Randomized Complete Block Design(RCBD) with three (3) replications over (18) number of experimental plots measuring 8x 3 m. The data collected was used to determine the performance of the developed planter for seedling emergence, plant spacing (inter row and intra row spacing), at a tractor forward speed of 7 km/h, 10 km/ha and 15 km/h respectively at a planting depth of 2 cm and 4 cm respectively. The data collected was computed and analyzed using the statistical analysis system (SAS software, version 9.4) statistical package.

The developed planter was attached to the three-point linkage of the tractor(EICHER 5660, 50hp) for field operation with the most commonly grown soybean variety(TGX 1951-3F). The planting was done after the land preparation operations.

I. . The collected data in the field were subjected to statistical analysis using Statistical Analysis System (SAS software, version 9.4)

II. The developed planter had an average of 92.3 % of the total number of seeds that emerged after planting.

III. The developed planter had an average of 5.7 cm of intra-row spacing which was the closest to the designed spacing of 5cm and thus has the ability of ensuring highest soybean plant density as recommended by International Institute of Tropical Agriculture (IITA, 2020) when used in planting.

IV. The evenness of plant spacing was 0.578 for the developed planter.

V. Speed of planting was found to be 0.6 m/s which is similar to Upahi(2017)

VI. Seed delivery rate for the developed planter was 48.2 kg/ha, which is similar to Agidi et.al, (2017) of 47.7 kg/ha and is closed to the recommended seeds rate per hectare(50kg/ha) as reported by IITA(2020)

VII. The overall field efficiency of the developed planter was 76.6 % and an effective field capacity of 1.14 ha/h.

5.2 Conclusions

I. A Four-Row Tractor Mounted Soybean Planter with effective field capacity of 0.792 ha/h was designed based on the recommended agronomic practices.

II. A Four-Row Tractor Mounted Soybean Planter has been fabricated using locally available materials to plant commonly grown soybean (TGX1951-3F) variety in the Northern Nigeria.

III. The developed planter was evaluated both in the laboratory and on the field.The developed planter has the capacity for planting single seed per hole in one hectare. Seedling emergence under the developed planter was estimated to be about 400,000 per hectare.The field capacity for the developed planter were 1.14 ha/h. The best tractor forward speeds of planting were 15 km/h and at 2 cm depth. The average intra row spacing was 5.7 cm for the developed planter.Therefore, I concluded that the Developed four-row Tractor Mounted Soybean Planter was efficient, affordable for optimum soybean plant population per hectare.

5.3 Recommendations

From the studies, the following recommendations were made:

I. The planter could be useful for medium and large-scale growersof soybeans

II. The planter can be best used at 15 km/h forward operating speed and at 2 cm depth of planting

For further improvement ofthe developed soybean planter the followings are recommended:

I. Fertilizer application components should be attached to the planter on each row

II. Perfect machining work should be done on the metering disc as well as on its casing.

III. Optimize the performance of the developed planter.

5.4 Contribution to Knowledge

I. A four-row tractor mounted soybean planter has been developed and evaluated

II. Appropriate operating speed and depth of sowing have been established.

REFERENCES

Abubakar, L.G. (1994). A Multi-Crop Rotary Jab Planter for Sandy Loam Soils. An unpublished MSc. Thesis Submitted to the Department of Agricultural Engineering, Ahmadu Bello University; Unpublished: page 168

Adisa, A. F, andBraide, F. G (2012), "Design and Development of Template Row Planter, *Transnational Journal of Science and Technology* edition.vol2(7):27-33

Agidi, G. Andrew, I. and Simon, M. I (2017); Design, Fabrication and testing of a tractor drawn soybean planter.*FUW Trends in science & Technology Journal*, www.ftstjournal.com e-ISSN; 24085162; P-ISSN; 20485170; April,2017; vol. 2 (1B): 562-568.

Al-Gaadi, K. A. (2011) Performance evaluation of a cup belt potato planter at different operation conditions and tuber shapes.*American-Eurasian Journal of Agriculture and Environmental Science.*Vol.10(5):821-28.

Alhassan, E. A., and Adewumi, A. (2018). Development of a self-propelled multi-crop two rows precision planter : *a new design concept for the design of planter.October, 2018*. Page 349-358

Ani, O. A. B, Uzoejinwa, B. andAnochili, N. F.(2016). Design, construction and evaluation of a vertical plate maize seed planter for gardens and small holder farmers. *Nigerian.Journal of Technology. (NIJOTECH)*, vol35(3):647 – 655.

American Society of Agricultural Engineers (ASAE) (2005).*Standards Book*, ASAE, publications, USA 70-79.

Bharat, M. R. and Sidharth, D.(2014)Tyre modeling for rolling resistance " aster'shesis in automotive engineering, vehicle dynamics group, Chalmers. University of Technology, Sweden. page 24, (2014).

Bakhtiari, M. R. and Loghavi, M. (2009) Development and evaluation of innovative garlic clove precision planter. *Journal ofAgricultural Science Technology* vol**:** 11:125-36.

Bamgboye, A., and Mofolasayo, A.(2006).Performance evaluation of a tomorrow okra planter.*CIGR Journal*.Manuscript PM 06 002. Vol. VIII. July, 2006.

Barut, Z. B. (2008) Seed coating and tillage effects on sesame stand establishment and planter performance for single seed sowing. *App EnggAgri*vol.24(5): 565-71.

Bosoi, E.S., Verniaev, O.V., Smirnov, I.I. and Sultan-Shakh, E.G.(1988).*Theory Construction and calculations of Agricultural Machines;* Russian Translation Series 1: 233-275.

Biam, C. K., and Tsue, P. T. (2013). Profitability of Soyabean Production by Small Holder Farmers in Nigeria : *A Guide for Sustainable Food Security .vol 5*(30), 89–97.

Chhina R S (2010) *Studies on mechanical seeding of onion seed.*Ph.D. dissertation.Punjab Agricultural University, Ludhiana, India.Page 3 and 4.

Celik, A, Ozturk, I. and Way, T. R. (2007) Effects of various planters on emergence and seed distribution uniformity of sunflower.*Applied Agricultural Engineering.*Vol.23(1):57-61.

Dugje, I. Y, Omoigui, L.O, Ekeleme, F.Bandyopadhya, R, Lava, K. P. andKamara, A.Y.(2009).Farmers' Guide to Soybean Production in Northern Nigeria.International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, :21.

Foods and Agricultural Organization (FAO) (1994). *Testing and evaluation of agricultural machinery and equipment: Principles and practices*; FAO Agaric Services Bulletin 110:150-169.

Gaikwad, B.Sirohi, N. P. S. and Kumar, A. (2007) Studies on vacuum singulation of seeds for sowing nursery plug trays. *Journal of Agricultural Engineering Res. Vol.*44 (4):54-59

Gupta, C. P. and Totok, H. (1992)."Design and development of a direct paddy seeder.*Agricultural Mechanization in Asia, Africa and Latin America.Vol.23*, No. L; 23-27.

Hall, A. S, Hollwen, K.O.A.andLaughum, H. (1980).*Schaum's outline of theory and Problem of machine design.*Metricselection.McGrac-Hill Books Company. New York, USA. :112.

Huji, H. (2002): Determination of some physical and mechanical properties of cowpea and soybean.*Unpublished B.Eng. thesis of Agricultural Engineering Department A.B.U Zaria*.(Final year project reports):25.

Ikechukwu, I. B, Agidi, G. andIkechukwu.C.U. (2014).Design and fabrication of a single row maize planter for garden use.*J. Advance. in Engineering. Technology*.,vol.1(2): 1-7.

Imologie, S. M. (2018). Design , fabrication and testing of a tractor drawn soybean.*FUW Trends in Science and Technology Journal*, www.ftstjournal.com e-ISSN: 24085162; p-ISSN: 20485170; April, 2018: Vol. 2 No. 1B :562 – 568

Isiaka, M., Suleiman, M. L, El-Okene, A. M. I. and Muhammad,U. S. (2001). Development of two-row animal drawn seed planter; *Savannah Journal of Agric. Mechanization*vol.2(1) :25.

IITA (2020). International Institute for Tropical Agriculture, Guide to Soybean Production in Northern Nigeria.Revised Edition 2020.USA1D: I-8.

Iken. J. E. and Amusa, N.A. (2014) 'Maize research and production in Nigeria. Institute of Agricultural Research and Training (IARandT), ObafemiAwolowo University, PMB 5029, Moor Plantation, Ibadan.Nigeria-. March 2004 :302-307.

Jain, R. K., and Bal, S. (1997). Physical properties of pearl millet.*Journal of Agricultural Engineering Research*, *vol.*66(2):85-9l.

Kalay, K. Moses, S. C, and Ashok, K. (2015) The Design and Fabrication of a Manually Operated Single Row Multi -Crops Planter, *IOSR Journal of Agriculture and Veterinary science (IOSR-JAYS), 8*(1.0):I47-I58

Kamaraj, P. and Kathirvel, K. (2008) Development and evaluation of tractor operated belt type cotton planter. *Journal of Agricultural Engineering,* Vol. 45(1):69-72.

Karayel, D. Wiesehoff, M.Ozmerzi, A. Miller, J. (2006). Laboratory measurement of seed drill seed spacing and velocity of fall of seeds using high-speed camera system. Computers and Electronics in Agriculture; vol. 50(2):89-96.

Kepner, R. A.Bainer, R. and Barger, E. L. (1978), Principles of farm machinery.3rd Edition.West port. G; AVI publishing company Inc:345.

Khan, A.A,(2008). "Preplant physiological seed conditioning "Hort, Rev. 13: 131-181*Journal of Agriculture and Ecology Research International*, *vol.*9(4):2016; Article n.JAERI.29301 ISSN:2394-1073.

Khan, K. Moses, S. C.and Kumar, A.(2015).The design and fabrication of a manually operated single row multi-crops planter.*IOSR J. Agric. and Veterinary Science, vol.* 8(10): 147-158.

Khawar, J. Zahid,A.and Muhammad, F. '(2007). Maize: cereal with a variety of uses. DAWN-Businesshttp;/wwwdawn.com/200/03/12/ebr5.htm.: 5

Khurmi, R. S. and Gupta. J. K. (2005) "A Textbook of Machine Design " 14th. revised edition. Chapters *2,* 14 and 18. S. Chand & Company Ltd., Ram Nagar, New Delhi-110055:434-960

Kumar, K. N. Naaresh, K. andOjha, p. (1986). "Design, construction, and performance ot a manually-operated seeding attachment for an animal drawn cultivator" *Agricultural Mechanization In Asia, Africa and Latin America.* Vol. 17, No. 2 : 35-38.

Maduako, J. N and Hannan, M. (2004) Determination of some physical properties of three groundnut varieties, *Nigerian Journal of Engineering Technology*. 24(2):12-18

Muhammad, G. (2010) Landslide susceptibility mapping to inform land use management decision in an altered climate.Un published MSc. Thesis submitted to the Department of Civil and Environmental Engineering, Washington State University, U. S. A:21.

Murray. J. R., Tullberg, N.J., and Basnet, B. B.(2010), "Planters and their components; types, attributes, functional requirements, classification and description," Australian center for international agricultural research (ACIAR) monograph :121-200

Muzammal, R.Tasneem, K.Ashfaq, A. Syed, A.Wajid, F.Rasul, J. H. and Saddam H. (2014): Effect of planting time and cultivar on Soybean performance in semi-Arid Punjab, Pakistan. *Global Journal of science frontier Research (D*). Volume XIV Issue III Version I.: 41

N.C.R.P.S (1988): National Coordinated Research Project on soybean, Proceedings of 8th Annual National Soybean Conference at Makurdi, Nigeria. :55.

Oduma, O. Ede, J. C. Igwe, J. E. (2014) Development and performance evaluation of a manually operated cowpea precision planter.*International journal of engineering and technology,* 4(12):693-699

Olajide, O. G. andManuwa, S. I.(2014).Design, fabrication and testing of a low-cost row-crop planter for peasant farmers. *Proceedings of the International Soil Tillage Research Organisation (ISTRO) Nigeria Symposium*, Akure 2014 November 3 - 6, Akure, Nigeria, :94–100.

Parish, R. L. McCoy, J. E. and Bracy, R. P. (1999) Belt-type seeder for soybeans.*Applied Engineering journal,*Vol. 15(2):103-106.

Raheman, H. and Singh, U. (2003) A sensor for seed flow from seed metering mechanisms. *IE (I) Journal of Agricultural Engineering.*Vol. 84:50-55.

Rahman, L.Haque M. S. (1978). Cultivars of soybean in Bangladesh prospects and their chemical composition. Proc. Soybean Discussion Forum, Bangladesh Coordinated Soybean Res. Project; 23 November, 1978. :9.

Sahoo, P. K. and Srivastava. A. P. (2008) Seed pattern characteristics of different metering systems for soaked okra seed. *Journal of Agricultural Engineering*, V**ol.** 45(1):1-6.

Saleh, A. (2021): Development of a Multi-Crop Single-Row Hand-Push Planter. Faculty of Engineering, University of Nsukka.*Proceedings of the 2021 Sustainable Engineering and Industrial Technology*. ISBN 0000-0000.:C3-1 to C3-3.

Shnalenga, T. R. and Hatibu, N.(1991).'"Development-of low-cost, hand-operated planter".*Agricultural Mechanisation, in Asia. Africa and Latin Americavol.*22(3) :39 - 41.

Simona V. (2020): Statista Agriculture in Nigeria Statistics and facts. www: statista.com/topics/6729/agriculture/Nigeria.:6729

Singh, S. and Sharma, D. N. (2006) Technical feasibility of mechanical planting of sunflower seeds.*Journal of AgriculturalEnggvol.*43(2): 62-67

Smith, G. N. and Smith, I. G. N. (1988).Elements of Soil Mechanics, seven editions.Blackwell science, 37.

Soyoye, B. 0.Ademosun, O. C. and Olu-Ojo, E. O. (2016)'. Manually operated vertical seed- plate maize planter. *Agricultural Engineering International Journal.:CIGRvol*18(I4):70-80

Soyoye, B. 0.Ademosun, O. C., and Leo, A. S. (2018)'. Determination of some physical and mechanical properties of soybean and maize in relation to planter design.*Agricultural Engineering International Journal.:CIGRvol. 20.*(I):81-90

Srivastava, A.K. Goering, C. E. and Robrbach, R. P.(1993). *Crop Planting*; ASAE Textbook, ASAE Michigan 6:221-263.

Stoney, E. A.(1999). Study, on grain crops and their properties.*Journal of AgriculturalEngineering Research,vol*7(3):105-111.

Tijjani, A. (2017) Development and performance evaluation of a manually drawn planter.Unpublished B.Eng. thesis of Agricultural and Bio-Resources Engineering Department A.B.U Zaria3.

Ugwuoke, I. C. Gbabo, A. and Ikechukwu, 1.B. (2014).Design and fabrication of a single row maize planter for garden use.*Journal of Advancement in Engineering and Technology,* Volume 1. ISSN-.2348-2931

Upahi, E. J.(2017). Development of and performance optimization of a two-row engine propelled seed ridge planter; Ph’D thesis submitted to the Department of Agric. And Bio-Resources Engineering, Ahmadu Bello University, Zaria; Unpublished: 209 pp.

Wahab, M. A.Mondal, M. R. I. Akbar, M. A. Begum, F. (2002).Status of oil crop production in Bangladesh. Oilseed Research Center, BARI, Joydebpur, Gazipur-:1701-1805.

APPENDIX A:ENGINEERING DRAWINGS OF THE FOUR-ROW TRACTOR MOUNTED SOYBEAN PLANTER

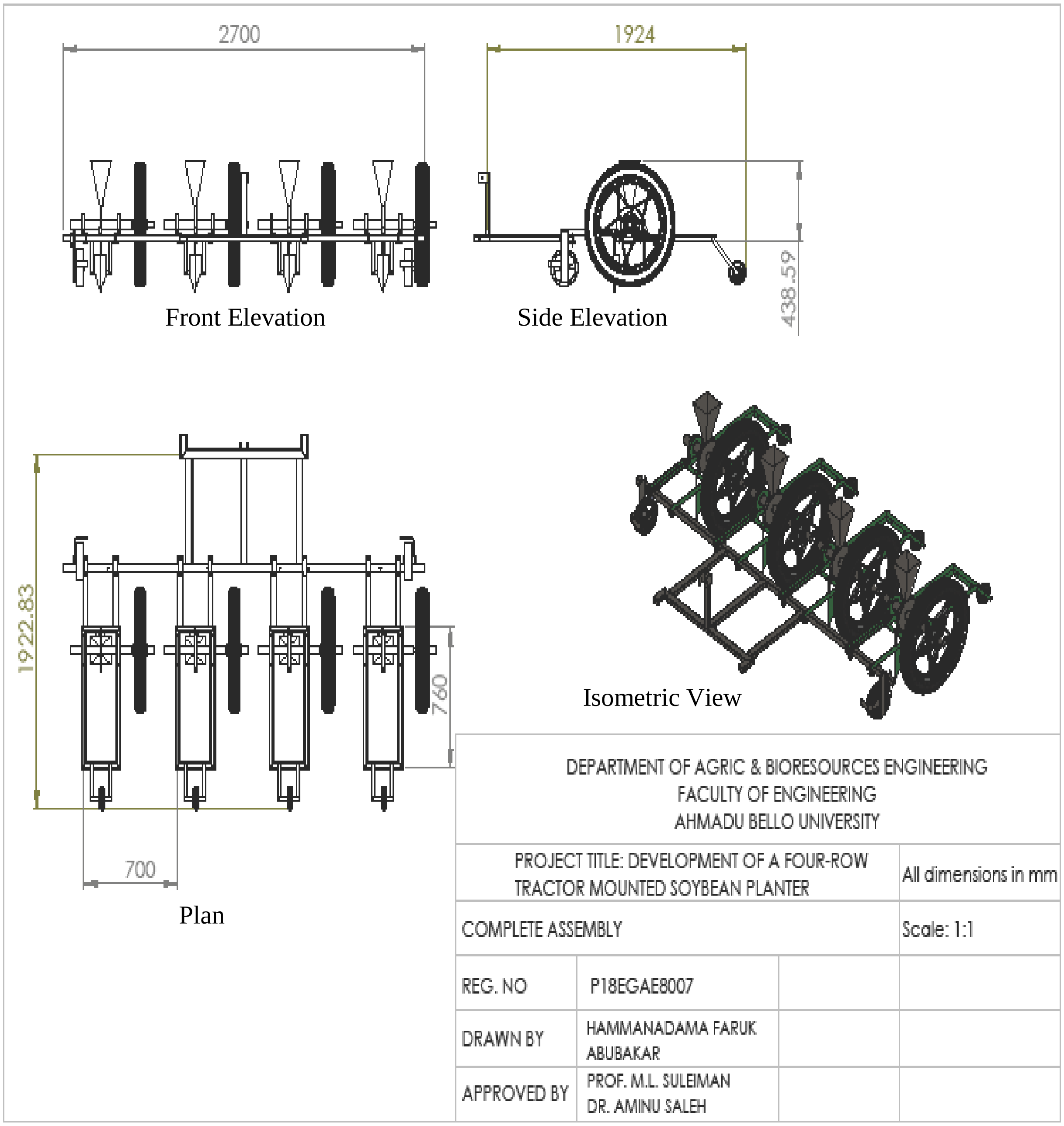
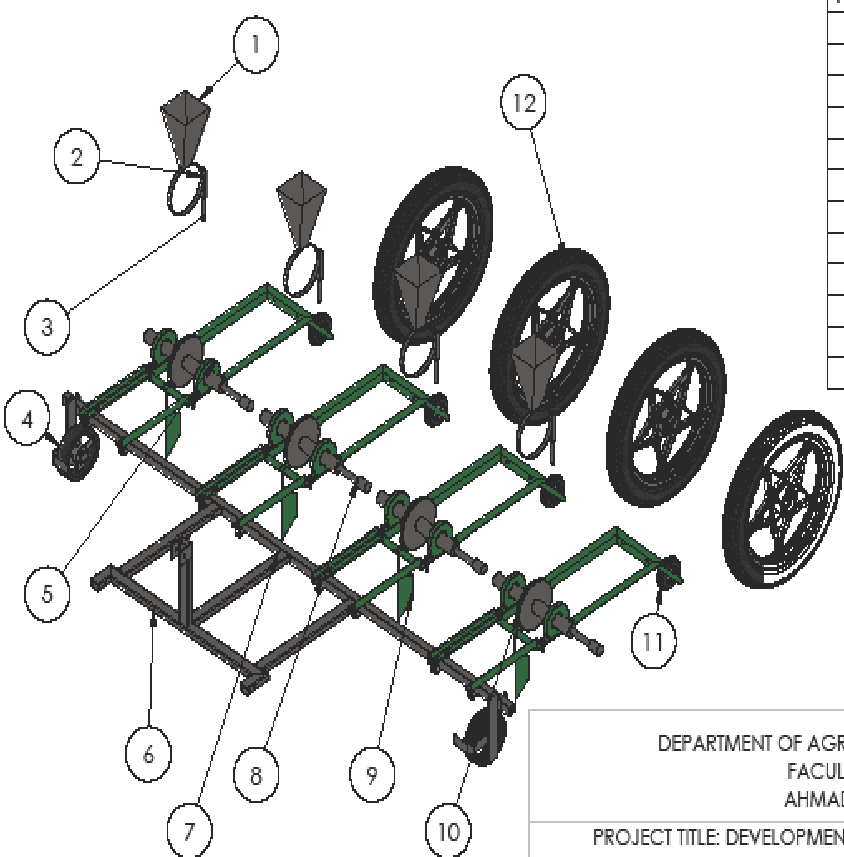


Figure A1: Orthographic projection of the soybean planter



Part Number	Part Name
1	Hopper
2	Metering Mechanism
3	Seed Droplet
4	Press Wheel
5	Bearing Housing
6	3 Point Hitch
7	Planter Frame
8	Shaft
9	Furrow Opener
10	Seed Metering Device
11	Furrow Closer
12	Wheel

DEPARTMENT OF AGRIC & BIORESOURCES ENGINEERING FACULTY OF ENGINEERING AHMADU BELLO UNIVERSITY			
PROJECT TITLE: DEVELOPMENT OF A FOUR-ROW TRACTOR MOUNTED SOYBEAN PLANTER			All dimensions in mm
EXPLODED VIEW			Scale: 1:1
REG. NO	P18EGAE8007		
DRAWN BY	HAMMANADAMA FARUK ABUBAKAR		
APPROVED BY	PROF. M.L. SULEIMAN DR. AMINU SALEH		

Figure A2: Exploded View of the Developed Planter

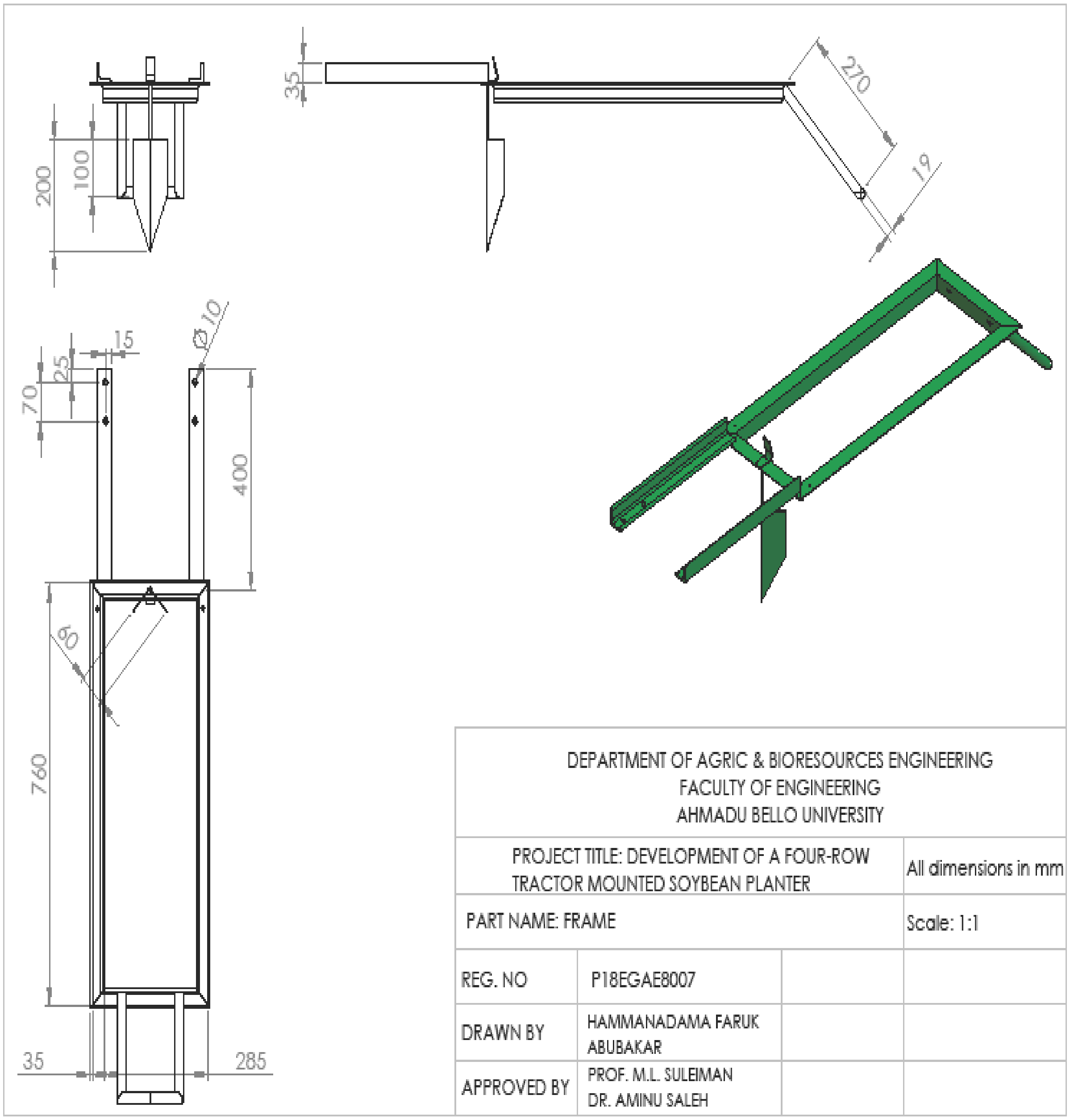


Figure A3: Frame of The Individual Unit of Planter

Appendix A: Developed Planter Three Point Hitch

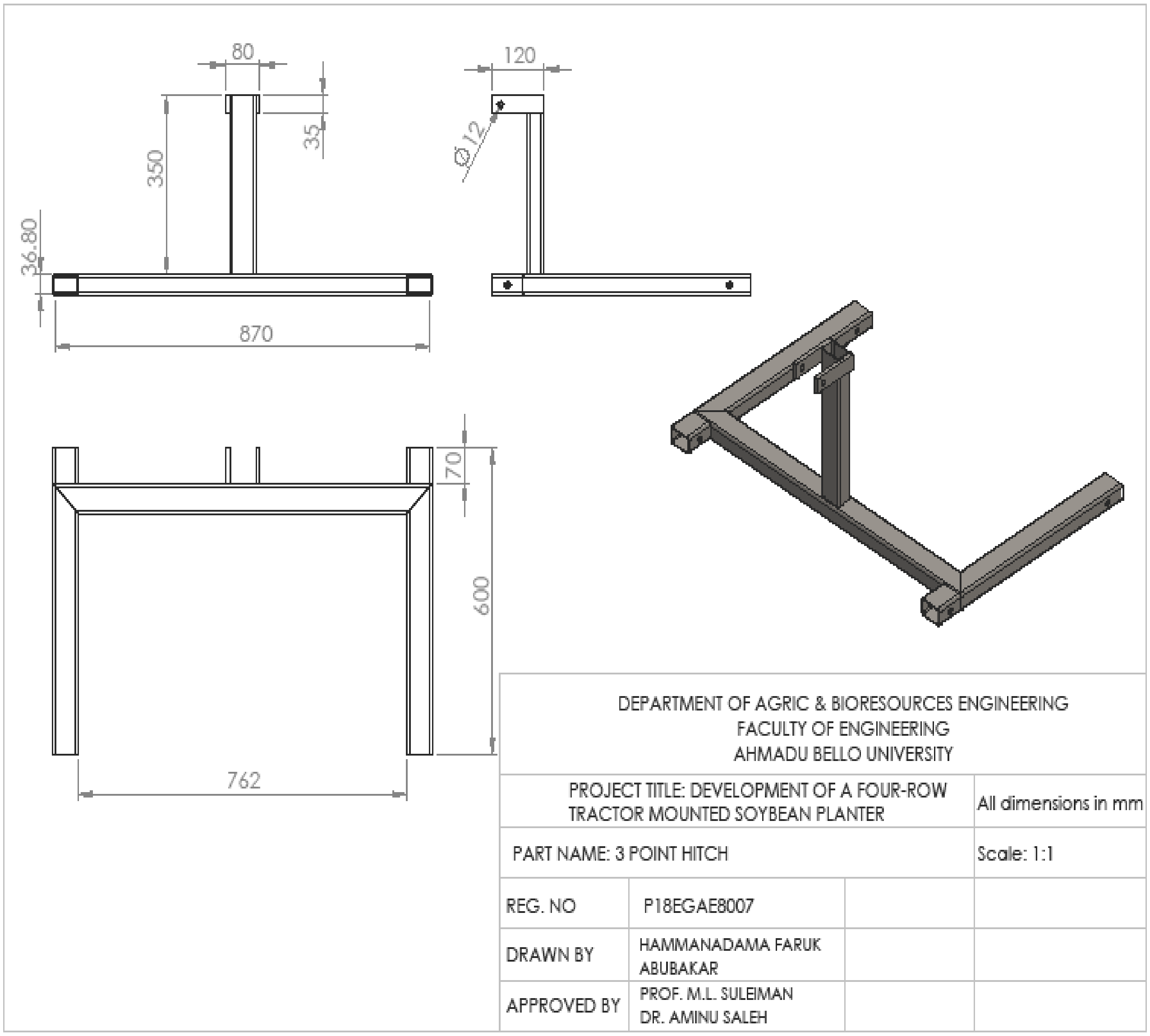


Figure A4: Developed Planter Three Point Hitch

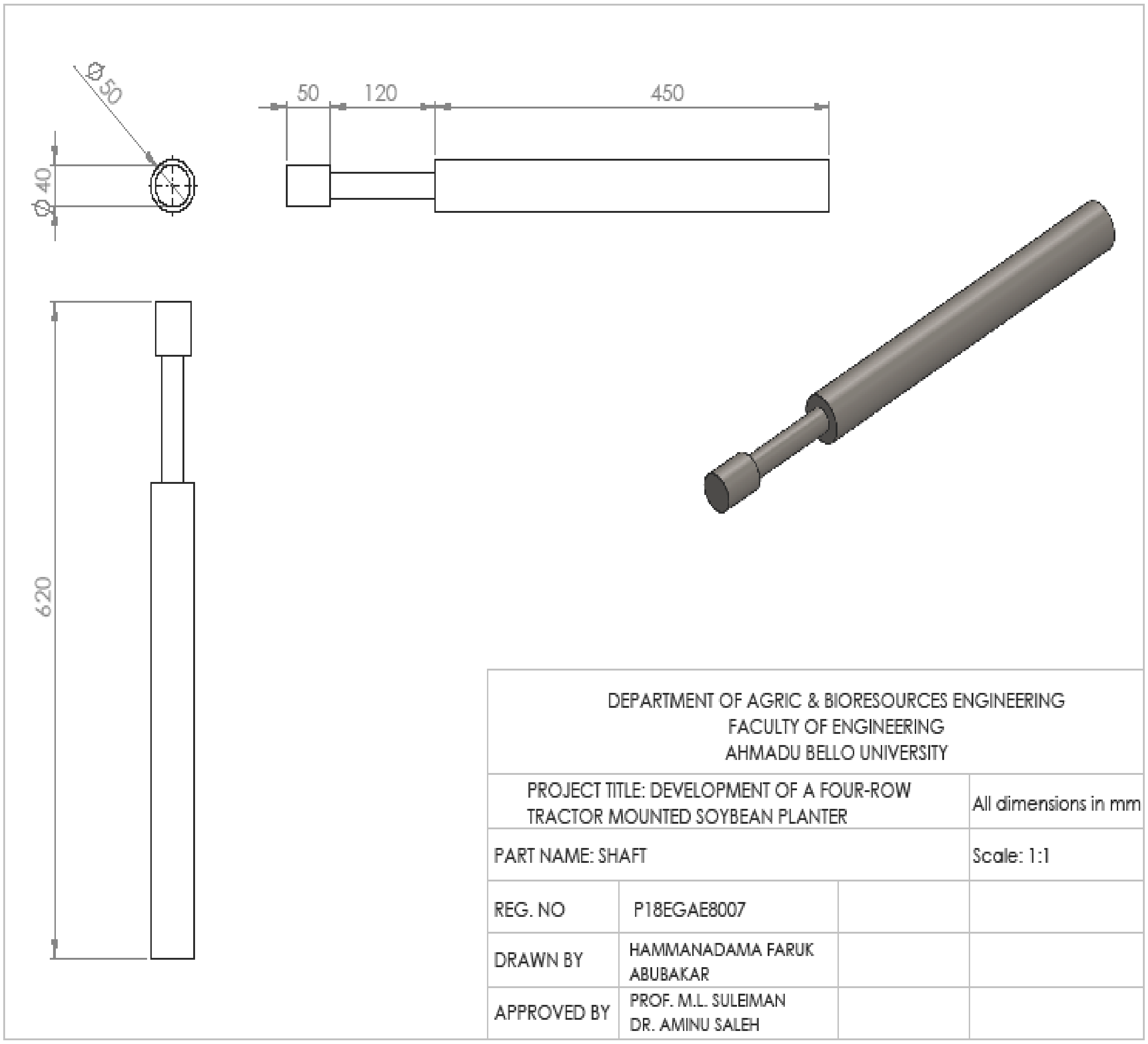


Figure A5: Shaft of the Developed Planter

Figure A6: Traction Wheel of the Developed Planter

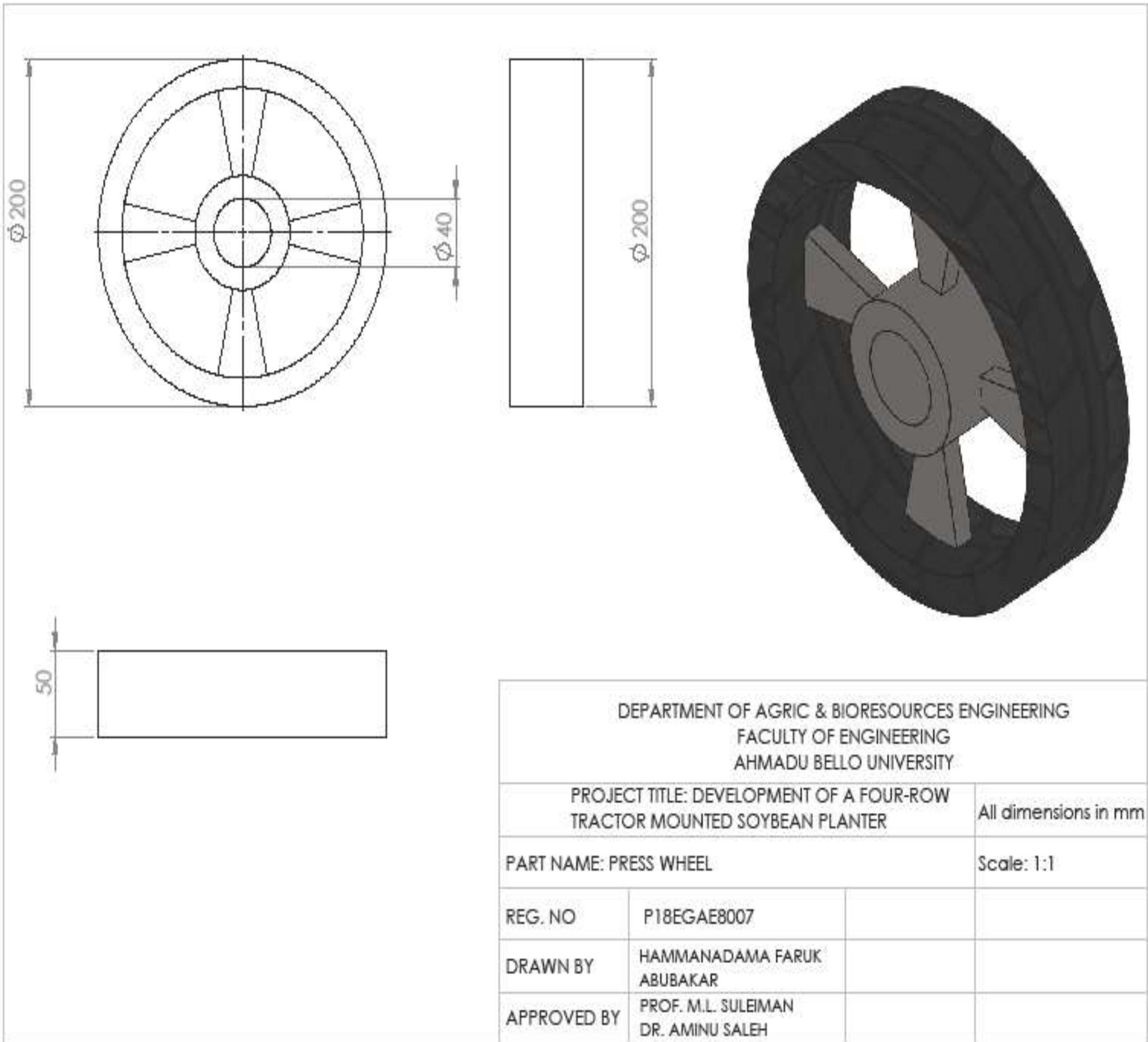


Figure A7: Press Wheel of the Developed Planter

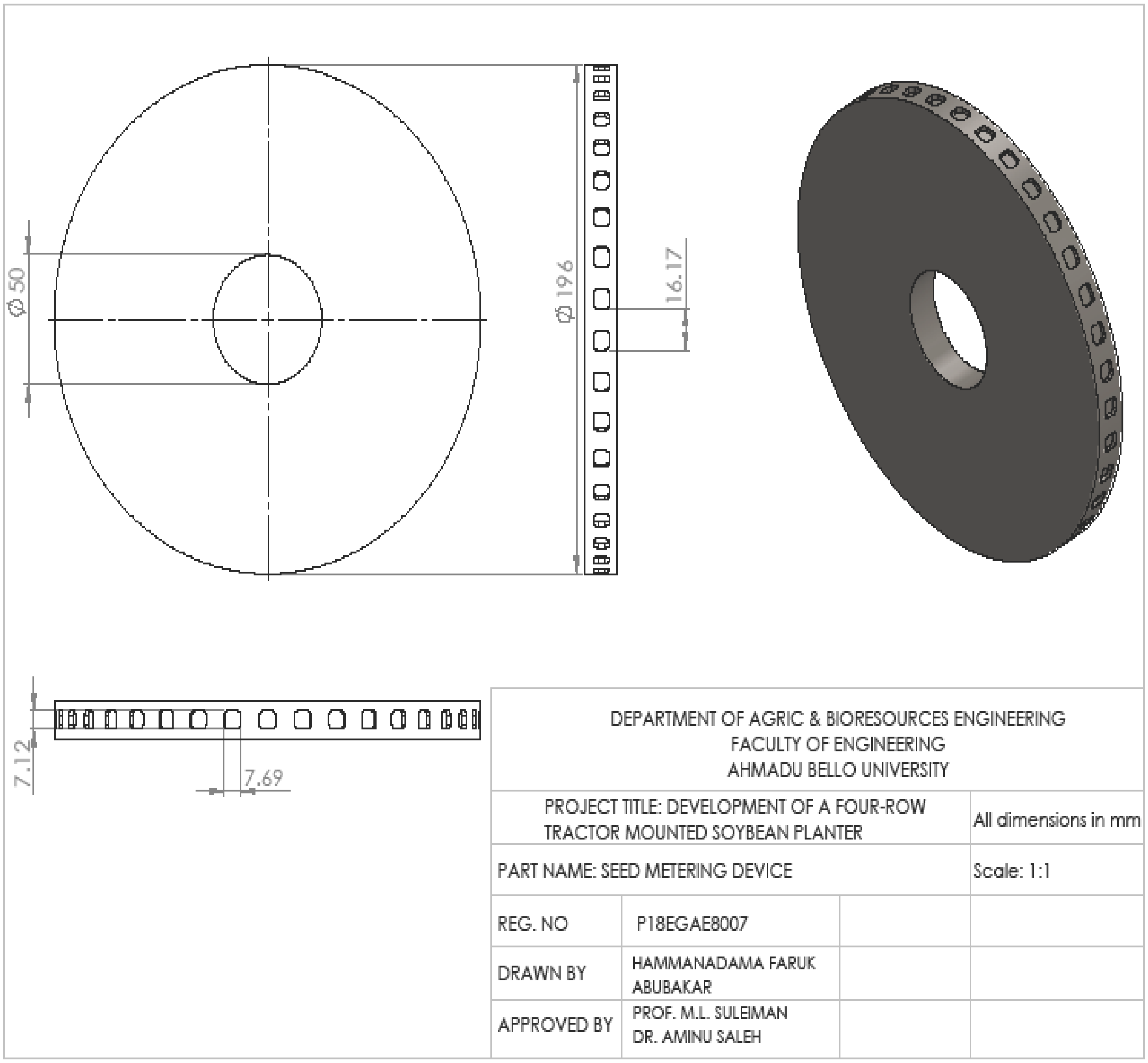


Figure A8: Metering Mechanism of the Developed Planter

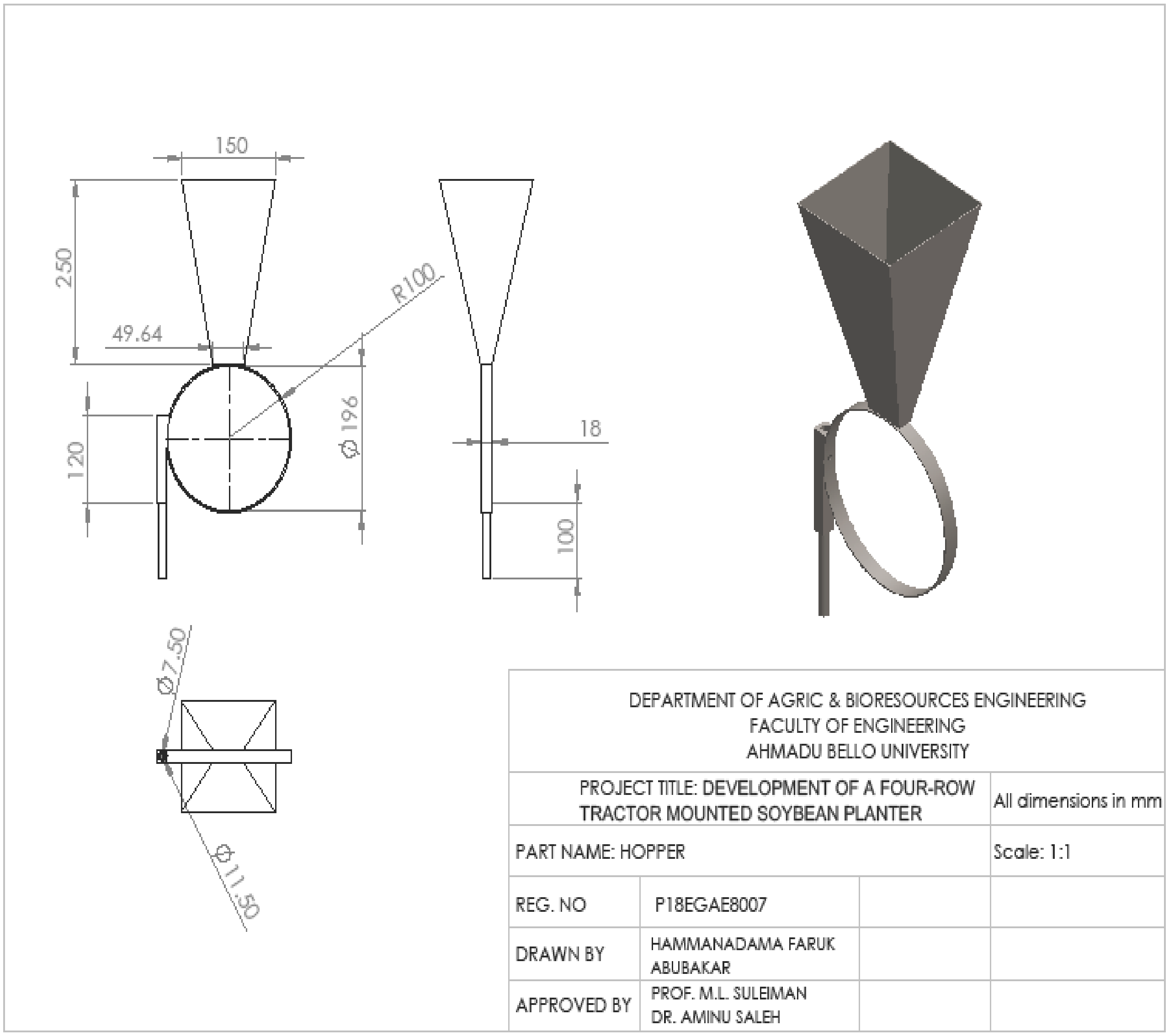


Figure A9: Hopper of the Developed Planter

Appendix B: Table 4.4 Physical and Mechanical Properties of Two commonly grown Soybean Varieties.

	TGX 1951-3F			**TGX 1448-2F**		
Parameter & Limits	**No of Sample**	**Mean Value**	**Standard Deviation**	**No of Sample**	**Mean Value**	**Standard Deviation**
Length (mm)	60	8.59	0.63	60	7.68	0.56
Width (mm)	60	7.09	0.59	60	6.16	0.51
Thickness (mm)	60	6.57	0.60	60	4.84	0.52
Weight (g)	30	0.19	0.05	30	0.18	0.05
Surface Area (cm^2)	30	5.24	1.09	30	4.73	1.01
Volume (mm^3)	30	103.9	14.8	30	95.5	0.11
Density (kg/m^2)	30	0.93	0.48	30	0.31	2.45
Sphericity	30	1.84	0.42	30	1.75	21.8
Roundness	30	0.83	0.09	30	0.79	0.03
Angle of Repose	20	18.50	4.19	20	16.85	0.39
Grain to Formice	20	5.10	0.86	20	7.43	0.13
Hardness (kg)	20	28.06	6.57	20	20.37	3.94
Compressive Strength(N)	20	98.65	13.62	20	105.30	14.5


Plate B1: Seed thickness determinationPlate B2: Seed length determination

APPENDIX C:

Table 4.1 Percentage seed damage.

	1st Hopper			2nd Hopper			3rd Hopper			4th Hopper		
Sample No.	Weight of whole seeds (g)	Weight of damage seeds (g)	% seed Damaged	Weight of whole seeds (g)	Weight of damage seeds (g)	% seed Damaged	Weight of whole seeds (g)	Weight of damage seeds (g)	% seed Damaged	Weight of whole seeds (g)	Weight of damage seeds (g)	% seed Damaged
Full hopper	2082	41.64	1.96	2080	39	1.84	2085	40.7	1.91	2078	35.8	1.69
Half-filled hopper	1041	8.41	0.80	1040	8.6	0.82	1042.5	7.8	0.74	1039	6.8	0.65
Quarterly filled hopper	520.5	6.02	1.14	520	5.7	1.08	521.25	4.8	0.912	519.5	5.3	1.01
Average % damage		1.394%			1.464%			1.460%			1.315%	
CV			45,87%			42.51			53.2			47.30

APPENDIX E: Germination count(Soybean Emergence)

Table 4.6: Field Evaluation Table on Soybean Emergence

S/N	REPLICATION	Treatment	Daily Plant Emergence					
			Day 1	Day 2	Day 3	Day 4	Day 5	TOTAL
1	REP1	D1S1	251	427	652	680	806	2816
2	REP1	D1S2	321	497	816	1202	1441	4277
3	REP1	D1S3	363	465	973	1083	1358	4242
4	REP1	D2S2	240	459	617	824	1157	3297
5	REP1	D2S3	321	456	584	694	961	3016
6	REP1	D2S1	265	504	730	940	1011	3450
7	REP2	D2S3	334	353	580	908	1137	3312
8	REP2	D2S1	245	354	401	652	980	2632
9	REP2	D2S2	222	412	661	682	997	2974
10	REP2	D1S1	285	406	506	694	905	2796
11	REP2	D1S3	386	709	796	874	1106	3871
12	REP2	D1S2	362	576	755	906	1013	3612
13	REP3	D1S2	395	601	722	926	1030	3674
14	REP3	D1S3	325	633	812	982	1395	4147
15	REP3	D1S1	315	391	523	698	804	2731
16	REP3	D2S2	310	403	504	612	921	2750
17	REP3	D2S1	317	421	506	607	820	2671
18	REP3	D2S3	305	611	621	804	1154	3495

Appendix D: Design Parameters

(i) Weight of the Planter

Weight of the planter component acting on the wheel $= W_m + W_h + W_{fr} + W_c + W_g$

Where;

$W_m = Weight\ of\ the\ metering\ plate$

$W_h = Weight\ of\ the\ hopper$

$W_{fr} = Weight\ of\ the\ frame$

$W_c = Weight\ of\ the\ metering\ casing$

$W_g = Weight\ of\ connecting\ bar$

$$w = \ell \times V \times g -------------------\text{Ei}$$

Where;

ℓ = density of the mater

V = volume of the material

But ℓ_m =960 kg/m^3 $\ell_h = \ell_{fr} = \ell_c = \ell_b$ = 7850 kg/ m^3

$$V_m = \pi h\,(R^2 - r^2) = 3.142 \times 0.04 \times (0.09652^2 - 0.01252^2) = 0.001151\text{m}^3$$

$V_h = 2 \times (A_l \times t + A_s \times t) = 0.000214$ m^3

$$V_h = 2 \times (A_1 \times t + A_s \times t) = 0.000214 m^3$$

Where;

$A_1 = area\ of\ the\ large\ plate\ of\ the\ hopper\ (m^2)$

$A_s = area\ of\ the\ small\ plate\ of\ the\ hopper\ (m^2)$

$t = thickness\ (m)$

$$\text{Area of the hopper plate (A)} = 2\left[\frac{1}{2}(a_1 + b_1)\hbar\right] + 2\left[\frac{1}{2}(a_s + b_s)\hbar\right]$$

Where;

a_1 = length of the small side of the large plate

b_1 = length of the large side of the plate

a_s = length of the small side of the small plate

b_s = length of the large side of the small plate

h = height of each plate

$$V_{frl} = V_l + V_b \text{-------------------} (Eii)$$

$$V_{fr1} = 2\,[Ll\,(2Bl)\,Tl\,] + 2[Lh(2Bb)Tb] = 2[0.32(2 \times 0.508)0.003] + 2[0.165(2 \times 0.08)0.003]$$

$$V_{fr1} = 0.000295656\ m^3$$

$$V_{fr2} = 2[L(2B)\,T] = 2[0.3(2 \times 0.0508)0.003] = 0.00018288\ m^3$$

$$V_{fr3} = 2[L(2B)\,T] = 2[0.2(2 \times 0.0508)0.003] = 0.00012192 m^3$$

$$V_{ala} = 2[L(2B)\,T] = 2[1(2 \times 0.0508)0.003] = 0.0006096\ m^3$$

$$V_{fr} = V_{fr1} + V_{fr2} + V_{fr3} + V_{ala} = 0.001210056\ m^3$$

$$V_{fr} = 0.001\ m^3$$

$V_c = \pi R^2 h - \pi r^2 h = 3.142 \times 0.05\ (0.1045^2 - 0.0975^2) = 0.000222\ m^3$

$$V_c = 0.000222\ m3$$

$$V_g = [(0.0508 \times 0.0508) - (0.0478 \times 0.0478)] \times 2.98 = 0.000881484\ m3$$

$V_g = [0.0478 \times 0.0478] \times 2.98 = 0.068088232\ m^3$

$$V_b = 0.000881484 + 0.0068088232$$

$$W_m = 960 \times 0.001151 \times 9.81 = 10.84\ N$$

$$W_h = 7850 \times 0.000214 \times 9.81 = 16.48\ N$$

$$W_{fr} = 7850 \times 0.001 \times 9.81 = 77.01\ N$$

$$W_c = 7850 \times 0.000222 \times 9.81 = 17.11\ N$$

$$W_b = [7850 \times 0.000881484 \times 9.81] + [1346 \times 0.0068088232 \times 9.81]$$

$$W_b = 67.88\ N + 89.91\ N = 157.79\ N$$

The weight (load) on the wheel of a single planter

$(W_1) = 10.84 + 16.48 + 77.01 + 17.11$

$W_1 = 121.44\ N = 13.27\ kg$

The total force exerted on the wheel and furrow opener of the four planter

$(W_4) = 121.44 \times 4 + 157.79 = 485.76 + 157.79$

$W_4 = 655.55\ N$

But for single planter $= 643.55 \div 4 = 163.89\ N = 16.80\ kg$

(ii) determination of the Torque on the Metering Plate

The required torque on the metering plate is obtained below

$$T_m = F_{md} \times r_{md}$$

Where, F_{md} = force produced by the metering plate

r_{md} = radius of the metering plate

$$T_m = 10.84 \times 0.0965$$

$$T_m = 1.046\ Nm$$

For the four metering plates we have $T_m = 4.184\ Nm$

(iii) Draft requirement for the tractor mounted planter

Total Draft requirements for the tractor mounted planter

$$= D_f + D_w - \text{iii}$$

$$D_f = R_s \times A_f \times g - - - - - - - - - - - - - - - \text{Eiv}$$

Where; D_f = draft of the furrow opener

$R_s = soil\ resistance$

$A_f = area\ of\ the\ furrow\ opener$

$g = acceleration\ due\ to\ gravity\ (9.81\ m/s)$

considering 2.0 cm soil depth

$$D_f = 0.385 \times (24 \times 2) \times 9.81$$

$D_f = 181.29$

$For\ the\ four\ planters\ D_f = 725.1552\ N$

(iv) Force Required to Overcome Soil Resistance

$F_{rs} = R_s \times Ac \times g$......................................(Ev)

$Where$;

$R_s = soil\ resistance$

$A_c = contact\ area\ of\ the\ wheel$

$F_{rs} = 0.385 \times (5.08 \times 2) \times 9.81$

$F_{rs} = 38.372796\ N$

$For\ the\ four\ planter\ F_{rs} = 153.491\ N$

3.5.5 Rolling Resistance of the wheel

$Rr = (1.2/cn = +0.04)W \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (Evi)$

$But\ cn = cl \times b \times d/W$

Where;

W = total force /load exerted on the wheel (N)

$\mathrm{Cl} = \text{cone index } (\mathrm{N/m^2})$

$\mathrm{b} = \text{width of the wheel (m)}$

d = depth of the wheel in the soil

Considering cone index for heavy clay soil which is 0.735 kg/cm², wheel depth of 2 cm and the wheel width (b) to be 5.08 cm

$Cn = cl \times b \times d/w = 0.385 \times 5.08 \times 2/16.40$

$Cn = 0.2385$

$R_r = (1.2/0.2385 + 0.04)\ x\ 160.89$

$R_r = 815.945\ N$

$For\ the\ four\ planters = 3263.780\ N$

(v) Torque on the wheel

$\text{Tw} = \text{F} \times \text{r}_w$

Where;

F = force required to overcome soil resistance (N)

$r_w = wheel\ radius\ (m)$

$T_w = torque\ on\ the\ wheel$

$T_w = 4996.56\ x\ 0.25$

$T_w = 1249.14\ Nm$

3.5.8 Total Torque

$T = Tw + Tmd$

$T = 1249.14 + 4.182$

$T = 1253.322$ Nm

(vii) Angular Velocity

$$\omega = \frac{2\pi n}{60} ------------------------- \text{Evii}$$

Where;

$n = Number\ of\ revolution\ (rpm)$

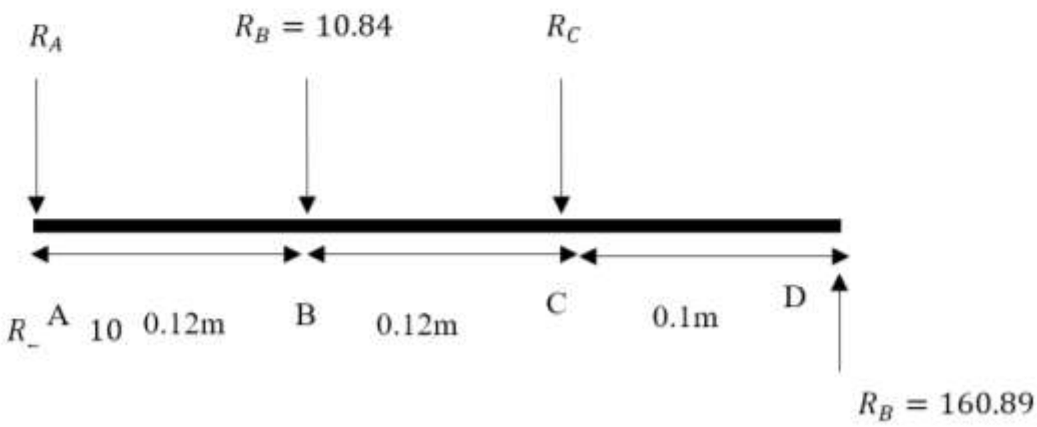
$\omega = angular\ velocity$

considering n for 1 revolution

$\omega = 2 \times \pi\, x \times 1/60$

$\omega = 0.105\ rad/sec$

(ix) Determination of the Bearing Reactions



The total load on the wheel = 160.89 N

Summing vertical forces = 0

$160.89 - R_C - 10.84 - R_A = 0$

$R_A + R_C = 150.05\,N ----------------- i$

Taking moment about R_D

$-R_A$ X 0.34 – 10.84 X 0.22 – R_C X 0.1 = 0

$$0.34R_A + 0.1R_c = --2.3848\,N ------------- ii$$

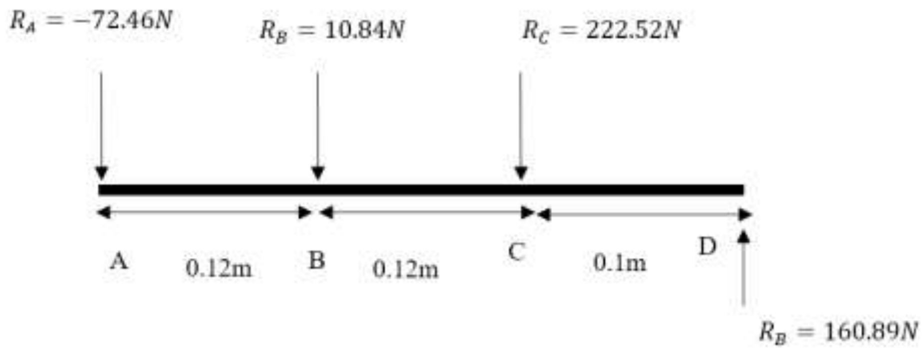
By eliminating R_C in Equation i and ii above

$R_A = -72.4575\,N$

Substituting R_A in to equation i

$R_c = 222.51\,N$

(x) Determination of Maximum Bending Moment



Where; R_D = reaction by the wheel

Weight of the metering device = 10.84 N

At point D

$BM = 0\ Nm$

At point C

$\text{BM} = -160.89 \times 0.1 = -16.089$ Nm

At point B

$BM = -160.89 \times 0.22 + 222.51 \times 0.12 = -8.69\ Nm$

At point A

$$BM = --160.89 \times 0.34 + 22.51 \times 0.24 + 10.84 \times 0.12 = 0.0006\ Nm$$

Therefore, the maximum bending moment M_b = 0.0006 Nm

The torsional moment of a single planter M_t = 299.22 Nm

(xi) Determination of the shaft Diameter

The shaft size was selected using the relationship given by (Khurmi and Gupta, 2006) as;

$d^3 = \frac{16}{\pi \tau s}\sqrt{(Kb\,M_b)^2 + (Kt\,M_t)^2}$……………………………(iii)

Where;

d = shaft diameter

K_b and K_t = combine shocks and fatigue factors applied to bending and torsional moment respectively

M_b and M_t = bending and torsional moment (N/m)

τ_s= allowable stress of the steel shaft (N/m²)

Allowable shear stress for the shaft without keyways, τ_s= least value of 0.3 yield strength and 0.18 ultimate strength of the shaft material (Khurmi and Gupta, 2006)

The material selected for the shaft is mild steel (C1040) with ultimate and yield strength of 770 and 580 MN/m² respectively.

$0.3(580) = 174 \text{ MN/m}^2$

$0.18(770) = 138.6 \text{ MN/m}^2$

The smaller value is 138.6 MN/m² and further reduced by 25% due to presence of keyway

$(1 - 0.25) \text{ x } 138.6 = 103.95 \text{ MN/m}^2$

Allowable shear stress for the shaft $\tau_s = 103.95 \text{ MN/m}^2$

$K_s = 1.5$ to 2.0

And $K_t = 1.0$ to 1.5

$$d^3 = \frac{16}{\pi \times 103.95 \times 10} \sqrt{(1.5 \text{ x } 0.0006)^2 + (1.0 \text{ x } 299.22)})^2$$

$$d = 0.0253\ m$$

$$d = 25.3\ mm$$

Therefore, a shaft of 25 mm diameter was selected and used for the developed planter.