ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

MECHANICAL SYSTEMS AND VEHICLE ENGINEERING PROGRAM

DESIGN, FABRICATION AND PERFORMANCE EVALUATION OF TWO ROW ANIMAL DRAWN SORGHUM PLANTER WITH FERILIZER APPLICATION

Thesis Submitted to the Mechanical Systems and Vehicle Engineering Program for the partial fulfillment of the requirements for the Award of Master of Science in Agricultural Machinery Engineering

PREPARED BY

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MAY, 2017

Adama, Ethiopia

CANDIDATE'S DECLEARTION

I hereby declare that the work which is being presented in the thesis entitled "Design, Fabrication and Performance Evaluation of two row Animal Drawn, sorghum row planter with fertilizer application" for the partial fulfillment of the requirements for the award of the degree of Master of Science in Agricultural Machinery Engineering is an authentic record of my own work carried out from May 2016 to March 2017 under the supervision of Simie Tolla (Dr. Ing) and Fekadu Lemessa (Dr. Ing), Department of Mechanical Systems and Vehicle Engineering Program, Adama University, Ethiopia.

The matter embodied in this thesis has not been submitted by me for the award of any other degree or diploma. All relevant resources of information used in this thesis have been dully acknowledged.

Name Tamrat Lema Nurgie Signature_______ Date ____________

ADVISOR'S DECLEARTION

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief. This thesis has been submitted for examination with my approval.

Major Advisor: Simie Tolla (Associate Professor) Signature_______ Date _________

Co - Advisor: Fekadu Lemessa (Associate Professor) Signature_______ Date _________

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TAMRAT LEMA

APPROVAL BY BOARD OF EXAMINERS

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DEDICATION

I dedicate this piece of work to my dearest family for their consistent and unreserved help, support, prayers for my success and encouragement with selfless scarifies throughout my educational career.

LIST OF ABBREVIATIONS AND ACRONYMS

A_f	Mean flat surface area
A_m	Area of the wheel calculated based on the median diameter of the wheel
ANOVA	Analysis of Variance
AIRIC	Agricultural Implements Research and Improvement Center
ASME	American Society of Mechanical Engineers
A_t	Mean transverse surface area of the individual seed
AWHP	Annual working hours of the planter
ρ_b	Bulk density of the seeds
CC	Capital cost
CBD	Complete Block Design
CRS	Cost of repairs and spares
CSA	Central Statistical Agency
CV	Coefficient of Variance
d	Diameter of the shaft
D1	Diameter of seed metering plate
D2	Diameter of ground wheel
D_a	Arithmetic mean diameter
DAP	Di Ammonium Phosphate
D_g	Geometric mean diameter
DLW	Daily labor wage
D_m	Major diameter of seed
DOW	Daily oxen wage (EB/h)
Dp	Depreciation
DWH	Daily working hours (EB/h)
EARO	Ethiopian Agriculture Research Organization
E_C	Effective field capacity
EL	Estimate life (h)
FDRE	Federal Democratic Republic of Ethiopia
G	Modulus of rigidity, 80.8GPa for steel
g	Acceleration due to gravity, m/s2

GDP	Gross Domestic Product
GFPC	Grams of fertilizer per cell
I	Interest %
IC	Interest on capital (EB/h)
I_{rss}	Intra-row spacing of plants
J	Polar moment of inertia.
K_b	Combined shock and fatigue factor applied to bending moment
Kg/ha	Kilogram per hectare
K_t	Combined shock and fatigue factor applied to torsional moment
L_m	Mean Length of seed
LSD	Least Significant Difference
LW	Labor wages
m	Number of scoops on a metering plate
MARC	Melkassa Agricultural Research Center
M_b	Bending momentum
M_h	Horizontal bending momentum
MISI	Miss index
M_t	Torsional moment
MULT I	Multiple index
M_v	Vertical bending momentum
N	Speed of the shaft
n	Number of refilling per hectare
NAOHP	Number of the annual operational hours of the planter (EB/h)
P	Power required to driving the machine
P_p	Plant population per hectare
PREC	Precisions index
QFI	Quality of feed index
RCBD	Randomized Complete Block Design
R_i	Inner radius of the wheel
Rm	Median radius of the wheel
R_o	Outer radius of the wheel

SD	Standard Deviation
Smf	Mean forward speed
Sm	Mean sphericity
S_R	Seeding rate
Ss	Allowable stress
SSA	Sub-Saharan Africa
SVC	Selvage Cost
t	Mean thickness of seed
D	Distance between consecutive scoops
T_e	Effective operating time
T_t	Total time
t_w	Thickness of the wheel
USDA	United States Department of Agriculture
V_m	Mean volume of seed
V_b	Theoretical Volume of seed box
V_D	Designed volume of hopper
V_S	Volume of the seeds in the hopper
W	Mean width of seed
W_e	Implement effective width
WO	Wage of oxen
Ɛ	Field efficiency
ⱱ	Poisson's ratio
τ	Shear stress, MPa

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ABSTRACT

Sorghum is a staple food crop for many of the Ethiopian's so, millions of poor Ethiopians depend on the crop. As a result, Agricultural sector requires modern techniques and suitable agricultural mechanization which will increase the production and productivity of sorghum, and reduce the level of manual labor, by introducing sorghum row planter to the target area. So, this study was undertaken to design, fabricate and evaluate the performance of a prototype animal drawn planter capable of planting sorghum seed at predetermined spacing and depths. The prototype could plant the seed with two rows, consisting of a frame, seed hopper, seed metering devices, seed tube/spout, drive wheels, furrow opener and furrow covering device. Even though the spacing between rows is adjustable it has been kept 70 cm. The planter have overall dimension 1210 mm x 605 mm x 648 mm and total weight of the machine was 59 kg. The average sphericity of the seed ,seed rate, seed damage and seed germination under laboratory testing of developed sorghum planter were found to be 84.34%, 15.08kg/hr, 0.67% *and* 99.16% *respectively. Field data on performance parameters of the planter was collected and analyzed. The mean value of multiple index , miss index, quality of feed index, precision index, actual field capacity, field efficiency and planting depth were found to be* 16.71%, 0%, 83.29%, 16.81%, 2.56 hr/ha, *80.03 % and 5.22cm respectively. Average speed of operation was 3.42 km/h and the average draft required to pull the multi crop planter was* 9.6 kgf. *The cost of the machine was determined as 7,071.55Birr. Based on the performance evaluation results, it was concluded that the prototype planter is efficiently, effectively and economically which can be used by the majority of farmers.*

1. INTRODUCTION

1.1. Background and Justification

Sorghum is a viable food grain for many of the world's most food insecure people who live in marginal areas with poor and erratic rains and often poor soils because of their good adaptation to hard environments and their good yield of production (AATF, 2011). The crop generally the most drought-tolerant cereal grain crops that require little input during growth and with increasing world populations and decreasing water supplies, represent important crops for future human use. It is the world's fifth most important cereal crop after wheat, rice, maize and barley and a staple food for more than half a billion people in the world, 60 percent of whom are in Africa (Kumara et al., 2011). The grain is a highly versatile crop with many uses including human food and animal feed, for brewing and bio-fuels.

In Africa, sorghum represents a large portion of the total calorie intake in many countries and it is the most widespread staple food crop. It is the second most important cereal (after maize) both in area coverage and production in Sub-Saharan Africa (SSA) (FAOSTAT, 2012). For millions of poorest and food insecure people in semi-arid tropics (SAT) of Africa, sorghum is the primary choice compared to the other crops for hot and dry agro-ecologies. This is because the crop is genetically suited to hot and dry agro-ecologies where it is difficult to grow other food grains. So, it is the food grain most widely grown and utilized for human consumption in the semi-arid regions of Sub-Saharan Africa (SSA). The crop also a major food and nutritional security crop to more than 100 million people in Eastern horn of Africa, owing to its resilience to drought and other production constrains (Gudu et al., 2013).

Ethiopia is the largest sorghum producing country, sixth globally and second in Eastern and Southern Africa next to Sudan. And the crop is a staple food crop on which the lives of millions of poor Ethiopians depend. In the county, sorghum is the fourth most important food crop after maize, wheat and tef in area and the second in total production next to maize and also it is the most important in the drier parts of the country (AATF, 2011). Sorghum is an indigenous crop to Ethiopia where it is grown in a wider area of adaptation ranging from hot, dry lowland to the cold highland environments. Annually, sorghum contributes 17% of the total cereal grain production of the country and is ranked third in both total area coverage and productivity (CSA,2014).

Sorghum is one of a traditional food crop widely grown in the country, in 13 of the 18 major agro-ecological zones, and in 2014/15 Maher season the crop covered an area of more than 1.8 million hectares and the production of the crop was over 43.3 million quintals (CSA, 2015). It has tremendous uses for the Ethiopian farmer and no part of this plant is ignored and it is used in various ways. The grain is used for human food in different forms in different part of the country. It is used as porridge, "Injera", "Kitta", "Nefro", infant food, syrup, and local beverages known as "Tella" and "Areke". Also the leaves and stalk are used for animal feed and further the stalk is also used for construction of houses and fences, and as fuel wood (MoA, 2010).

Despite this potential, sorghum production in the Ethiopian was 2.1 MT/ha, which is low by comparison with the crop's potential due to this, the country ranks 34th in yield even though, 5th in area harvested globally. This is because of the production method practiced in Ethiopia is traditional, underdeveloped, subsistence and small-scale (Bill and Melinda Gates foundation, 2014). The status of agricultural mechanization in the production line of sorghum such as starting from land preparation implements up to planting, harvesting, threshing and storage are very low. Almost all of the farm operations are performed with hand or using rudimentary hand tools and traditional animal drawn implements. From those the major mechanization problems, planting method is one; it was believed that this problem was created due to lack of suitable sorghum seeder/planter throughout the country, this is because of, in Ethiopia about 69% of smallholder farmers own farmlands less than or equal to one hectare in size and average grain yield for various crop is less than one metric ton per hectare (CSA, 2013), because of this, yield per hectare production of sorghum in the county is low.

The low productivity of sorghum in developing countries including Ethiopia can be attributed to many factors. Among these factors inappropriate plant population and low fertilizer application are the major ones which affect sorghum production (CSA, 2009). Plant population is a variable that can have a significant impact on the net returns of sorghum producers. It can impact the crop yield potential (Fernandez et al., 2012). Getting the required plant population by, using traditional planting method is very difficult, so using of appropriate planting machine is mandatory to get optimum plant population for higher yield.

It is very difficult for Ethiopian farmers to own and operate costly agricultural machineries that can establish the optimum plant population. Hence, in most part of the country, manual broadcasting or hand drill method of sowing is still in use. It is obvious that, this traditional method of planting cannot be uniformly distributing the seed and cannot be maintains the optimum plant density in the field; as a result, low efficiency, labor intensive and high costs are being incurred throughout the system.

Furthermore, the problem of using hand broadcasting and hand drill method of sowing is, both are require experienced manpower to broadcast or drill in order to get optimum plant population, so that planting by hand is difficult for inexperienced farmers. As a result, developing agricultural sector requires modern techniques and suitable agricultural mechanization which will increase the agricultural production and reduce the level of manual labor, which represents 85% of the total labor force, involved in agricultural sector (CSA, 2013). And introducing sorghum row planter to the target area is crucial for sorghum production and productivity.

In this study effort was made to solve problems observed in traditional sorghum planting method through design, fabrication, testing and evaluation of two row animal drawn sorghum row planter.

1.2. Statement of the problem

Sorghum is a highly valuable grain for Ethiopian people both in production amount and in consumption level. But, planting of sorghum is done by hand in almost all over Ethiopia this leads to low yields of sorghum per hectare. The causes among others include:

- Lack of uniform distribution of sorghum in field due to wind, human ability to distribute evenly
- Exposes seed for consumption by rodents and birds
- Waste of seed sorghum as the amount hand broadcasted is higher to overcome un even distribution to bring overlapping of sorghum sown
- Requires higher working hour to sown sorghum manually in row.

Even though sorghum is the staple food of most Ethiopian people, the present production system cannot satisfy the consumers' demand. This is due to the farming system that farmers use is backward which is not supported by modern technologies. This means the local people use hand broadcasting system rather than using mechanical seeding method. Traditional methods of crop planting have involved planting of excess seed and increase human drudgery. Therefore, a new, efficient planter that can easily be operated and suitable for different soil types and agronomic conditions with little modification had to be designed and developed in order to satisfy the demand of sorghum.

1.3. Objective of the study

General objective

The main objective of the study was to design, fabricate and performance evaluation of animal drawn two row sorghum planter.

Specific objectives

i. To study the physical properties of experimental seeds and generate data that could be used in the design and performance evaluation of the planter
ii. To design and construct each component of animal drawn planter for sorghum seed
iii. To test the performance of designed planting machine on the basis of seed spacing indexes, field efficiency and field capacity

1.4. Significance of the study

Ethiopia in particular, is repeatedly affected by food security problems due to lack of modern agricultural technologies. Farmers mainly produce sorghum through traditional broadcasting method with high seed rate. This cause yield reduction and lodging problem of the grain. Row planting method with reduced seed rate per hectare allows minimum competition between seedling and increase tillers of sorghum grain. So, the importance of design of sorghum row seeder is to increase production of sorghum through uniform distribution of sorghum seed in the field and also reduce cost of weeding, by providing uniform row; which gives opportunity to use mechanical weeder, as well saving the time, resources and money per hectare.

2. LITERATURE REVIEW

2.1. Production and Productivity of Sorghum

Ethiopia's agriculture is complex, involving substantial variation in crops grown across the country's different regions and ecologies. Five major cereals (teff, wheat, maize, sorghum and barley) are the core of Ethiopia's agriculture and food economy (Alemayehu et al., 2011). Ethiopia is probably the original home of sorghum and is the source of many wild and cultivated forms adapted to a wide range of growing conditions. Sorghum is one of the leading traditional food crops in Ethiopia comprising 15-20% of the total cereal production in the country (Wortmann et al, 2010). In Ethiopia, according to CSA, 2015 report, sorghum is the third important cereal after tef and maize in terms of area coverage and volume of production, and was grown on 1,831,600.45 ha and the yield produced during 2014/2015 "*Meher*" season was 43,391,342.61 quintals. The national estimated and expected average crop productivity of sorghum is 2.34 metric tons per hectare (USDA, 2014); this is lower than most of developed and some of African countries. This reduction is because sorghum cultivation in Africa is still mainly characterized by traditional farming practices; with low inputs (no inorganic fertilizer or pesticides), no improved agronomic practices and traditional varieties or landraces (Taylor, 2012).

2.2. Crop Establishment

Crop establishment is the sequence of events that includes seed germination, seedling emergence and development to the stage where the seedlings could be expected to grow to maturity. Establishment depends on the complex interaction over time of seed, soil, climatic, biotic, machinery and management factors (Wood, 1987; Miller et al., 1993). Many management activities such as irrigation, fertilizer application, pesticide application, etc modify the environment. Harvest techniques, seed storage method, pre-plant seed treatments, etc do modify seed properties. The selection, setting and operation of planting machines directly influence seedbed conditions and may cause mechanical seed damage (Gramshaw et al., 1993).

The planting machinery is usually critically important in crop establishment. Planting machines modify the pre-existing seed and soil conditions, and dictate seed placement within the seedbed.

An essential requirement of effective machinery management is to identify the main components of these machine-soil-seed interactions (Tessier et al., 1991).

2.3. Major Agronomic Operations of Sorghum Production

Seeding rates, planting time and planting depth are also the most important agronomic practices which have considerable influence on sorghum production. Seeding rates or plant populations vary depending on rainfall and growing conditions. Planting should also be timed so flowering avoids the hottest, driest period of summer. Planting too early results in delayed emergence and reduced stands. Late plantings may not allow the crop to mature. The optimum planting depth differs with soil types and moisture conditions. In heavier soils, a planting depth of 2.5 cm is satisfactory. In sandy soils, seeds can be placed 5 cm deep without problems (Shroyer, 1998).

2.4. Row Spacing

Row spacing plays a large role in crop production. Knowledge of the most productive row spacing for each crop can make a significant yield difference. Row spacing requirements depend on architecture and growth pattern of the varieties. For higher yield, higher proportion of incident radiation at the soil surface must be intercepted by crop canopy. If a row distance is too wide, solar radiation that falls between crop rows remains unutilized. On the other hand, plants become crowded and they suffer from mutual shading if the row distance is too narrow. Moreover, yield may be reduced in narrow spacing due to increased competition of plants for nutrient and moisture (Das and Yaduraju, 2011).

Selecting optimal row spacing is important to improve crop productivity as plants growing in too wide of a row may not efficiently utilize light, water, and nutrient resources. However, crops grown in too narrow rows may result in severe inter row competition. Row spacing also modifies plant architecture, photosynthetic competence of leaves, and dry matter partitioning in several field crops (Hussain et al., 2012).

2.5. Plant Population

Plant density is dependent on both row width and intra-row spacing and under dry land conditions row width plays an important role in determining plant density (Mashiqaa and Ngwako, 2011). Though the yield per plant is lower at closer spacing, greater number of plant per ha compensate the loss in the yield of individuals plant (Balasubramaniyan and Palanlappan, 2007). The optimum plant population varies and it is important to target a specific planting density (GRDC, 2005). And intra-row spacing should not be too narrow as this can increase competition between plants and results in yield detrimental effects (Mashiqaa and Ngwako, 2011). The best way to get uniform plant stands is to plant in regularly spaced rows and at regular intervals within the row (Faisul et al., 2013).

Grain yield increases linearly with plant density until some competitive effects become apparent. Effects of plant density normally refer to number of plants per unit area, but spatial arrangement of plants should also be considered. So, an appropriate plant stand may help in harnessing all the renewable and nonrenewable resources in a more and efficient manner towards higher crop yields (Ahmed et al., 2010).

Plant population can have either asymptotic or parabolic. In the asymptotic relation, yields increase linearly with increase population over the lower range of population. However, in parabolic the total yield decline at higher population and there is an identifiable optimum value (Mashiqaa and Ngwako, 2011). The best way to get uniform plant stands is to plant in regularly spaced rows and at regular intervals within the row (Faisul et al., 2013).

2.6. Crop Yield

Studies in different parts of the country have shown that seeding devices introduced in rain feed areas have increased crop yields by 10 to 20 percent over conventional methods of seeding due to better plant establishment and proper application of inputs(Mehta and Varshney, 1970). Research indicates that the percent of grain sorghum yield lost from weed competition exceeds that of most other grain crops. Losses typically range from 30 to 50%, but can be much greater under extreme densities and drought conditions (Stahlman and Wicks, 2000)

2.7. Timeliness of Operations

Timeliness of operations is one of the most important factors which can only be achieved if appropriate uses of agricultural machines are made. Increases in crop yield, cropping reliability, cropping frequency and crop returns all depend on the uniform and timely establishment of optimum plant population. Planters place seeds at required spacing and provide better growing area per seed (Karayel, 2009).

Thus, it is important to improve the planting operation by reducing human effort, and increasing stand accuracy and field capacity. Furthermore, developing agricultural sector requires modern techniques and suitable agricultural mechanization which will increase the agricultural production and reduce the level of manual labour, which represents 85% of the total labor force, involved in agricultural sector (CSA, 2013). Nonetheless, Ethiopia as a nation and the Ethiopian farmers, as the major section of the population, lacks the means to establish optimum plant population of almost all crops timely.

2.8. Physical Properties of Seeds

The physical properties of seeds are essential in the design and development of specific planting machine components. Seed metering devices, which are moving or stationary members have indents, i.e. scoops or cells and the metering performance highly dependent on the compatibility between cells/scoops and seeds size and shape. Hence, knowledge of the shapes and sizes of seeds, in terms of seed length, seed width and seed thickness, and mean diameter and sphericity, are essential in the design of metering devices and sizing of cell (Konak et.al, 2002).

The fluted-roller seed meter is capable of metering seed uniformly and is commonly used as metering device for drilling of small grain but is negatively impacted by sudden release of seed batches (Maleki et al., 2006). The conventional fluted meters for drilling often resulted in poorly spaced stands with many gaps. To compensate for this stand variability, many operators over-seed small grains by 10-20 percent. Research shows that the conventional fluted-meter devices evaluated for variable-rate seeding are not very accurate. Fluted meters have a cup on a rotating shaft and an opening gate. The result shows that changing the shaft speed, forward speed, or gate opening greatly hinder the accuracy of population and spacing of the seed. With the increase in seed size the variability was even greater. (Satti et al., 2012).

The popular and widely used horizontal seed metering is having several problems, including higher seed damage, missing and multiple drops (Singh et al., 2005). Inclined and vertical plate planters were developed and used further to reduce these losses

Various types of design have been developed with different design approaches which have their advantages and disadvantages and also operational limitations. Ranjeet Kumar, 2015 conducted experiment on Performance evaluation of a tractor mounted pneumatic planter for sorghum in dryland and they concluded that the pneumatic planter was found suitable for sorghum with the best suited gear combination, that is, gear having 14 teeth mounted on the axle of ground wheel and 20 gear teeth mounted at the ends of the primary driving shaft with 14 gear teeth mounted at the middle of the primary driving shaft of pneumatic planter with tractor PTO shaft speed of 550 rpm. Performance of the pneu-matic planter was evaluated in the field and the average values of plant to plant spacings, mean miss index and multiple index, actual field capacity and field efficiency were found to be 101 mm, 2.07%, 3.8%, 0.77 ha/h, 79.7%, respectively. All the observed values were within the recommended levels. Hence, this planter was found suitable for planting of sorghum seeds in dry land

Ashebir, 2015 conducted experiment on development of animal drawn multicrop planter in order to handle maize, haricot bean and sorghum seeds. The prototype planter had three different and yet inter-changeable seed metering rollers. He recommended that the speed of the planter should not exceed 5 km/hr in order not to seriously and negatively affect the percent cell fill or the recommended plant population. And the highest percent seed damage was observed with sorghum seeds; hence care must be taken when designing metering devices to handle sorghum seeds.

The planters available in the market outside the country are expensive, not suited to local conditions and they are mostly designed to operate in large farms, Hence, this thesis project would be designed to bridge the existing technology gaps in the area of crop establishment, achieving uniform seed sowing depth, seeding rate and seed spacing in the row with prime objective of design, fabrication and performance evaluation of two row animal drawn sorghum planter

3. MATERIALS AND METHODS

3.1. The Experimental Site

The Field and laboratory experiments were conducted at Melkassa Agricultural Research Center (MARC), 17 km South of Adama, or it is located 117 km South East of Addis Ababa, Ethiopia. Melkassa has a highly variable rainfall that ranges between 500 and 800 mm annually. The agro-ecology is termed as Kolla (Warm, semi-arid lowlands). The dominant soil type in the area is sandy loam. Because of its agro-climatic condition, most varieties of sorghum crop grow well in the area. Fabrication of prototype and any adjustment or maintenance also conducted in AIRIC workshop, which is found in the center.

3.2. Materials used for experiments

The materials and tools used for this project include, the mechanical Engineer drawing instrument, reinforcing iron rod, angle iron, flat steel bar, sheet metal, chain and sprockets, bearings, drilling machine, grinding machine, were used during the construction of the prototype. In addition to these, small plastic bags, weight balance (0.1gm accuracy), digital caliper of 0.01 mm accuracy, measurement tape (with millimeter graduation) and stop watch instruments, 50 kg of sorghum seed and 100 kg fertilizer were employed during the field and laboratory experiments.

3.3. Determination of Physical Properties of experimental crop

Identifying the physical and engineering characteristics of experimental crop grains is very important to optimize the design parameters of agricultural equipment. The crop, sorghum, was selected for the study. So, it is essential to determine and recognize the database of physical and engineering properties of this crop because these properties play an important role in designing and developing of planting machine, also to determine the optimum in seed metering device in precision planting machine to suite every size of these grains.

Sorghum seed was used to evaluate the performance of the prototype planter fabricated at ARICI, MARC. The selected crop is taken from Sorghum Research Process, which is found in the center, had 74% of germination. In addition to this, the shape of the seed is described in terms of its volume, geometric diameter and sphericity; these were taken into consideration during the construction of the Planting Machine.

The seeds were cleaned manually to remove all foreign matter such as dust, dirt, stones and chaff before determine the mean size of the seeds, used in the study then the grain dimensions were determined by randomly selecting 50 seeds from the representative samples and measuring their three principal diameters length (L), width (W) and thickness (T) using digital caliper of 0.01 mm accuracy and the 1000 seeds mass was measured by an electronic digital balance to an accuracy of 0.0001g. The mean sizes of 50 seeds were determined as geometric mean diameters and the data were important for the determination of the scoops size on the seed plate. The same analysis was done for the fertilizer except that instead of measuring the dimensions of the fertilizer grains, it was the average weights of 10 grains of fertilizer were calculated from 200 randomly selected DAP fertilizer grains. The geometric diameter, volume and sphericity of the individual seeds were calculated using the measured length, width and thickness of the seeds and equations given below (El-Raie et al., 1996).

$$D_g = \sqrt[3]{(L_m \times \mathrm{W} \times \mathrm{t})} \quad \ldots\ldots 3.1$$

$$V_m = \frac{\pi}{6}(L_m \times \mathrm{W} \times \mathrm{t}) \quad \ldots\ldots 3.2$$

$$S_m = \frac{\sqrt[3]{(L_m \times \mathrm{W} \times \mathrm{t})}}{L_m} \times 100 \quad \ldots\ldots 3.3$$

Where:-

L_m = Mean length, (mm)

W = Mean width, (mm)

t = Mean thickness, (mm)

V_m = Mean volume, (mm^3)

D_g = Mean geometric diameter, (mm)

S_m = Mean seed sphericity, (%)

3.4. Design of the planter

3.4.1. Description of the planter Components

The developed two-row sorghum planter consists of frame, seed and fertilizer hoppers, metering mechanisms, furrow openers, furrow covering devices, drive wheels and handle. Generally the total weight of the planter at full loads of the seed and fertilizer hoppers is 59kg so as to create enough traction between the wheels and the ground, and also to avoid any skidding/sliding of the wheels over the ground when the planter is drawn by donkey or a pair of oxen and as shown in the fig. 2 the planter have overall dimension of 1210 mm × 605 mm ×648 mm.

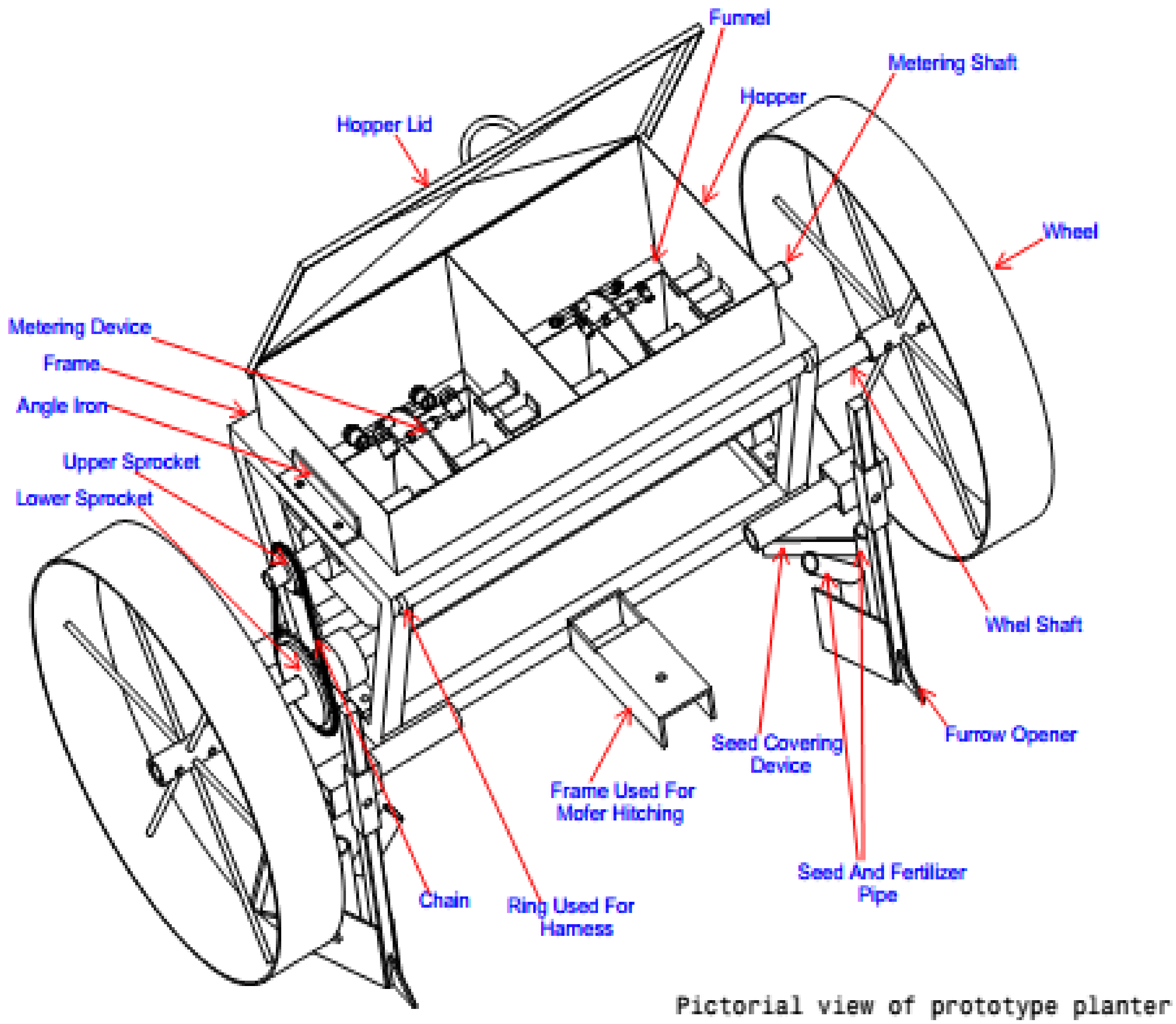


Fig. 1 Pictorial view of the prototype planting machine

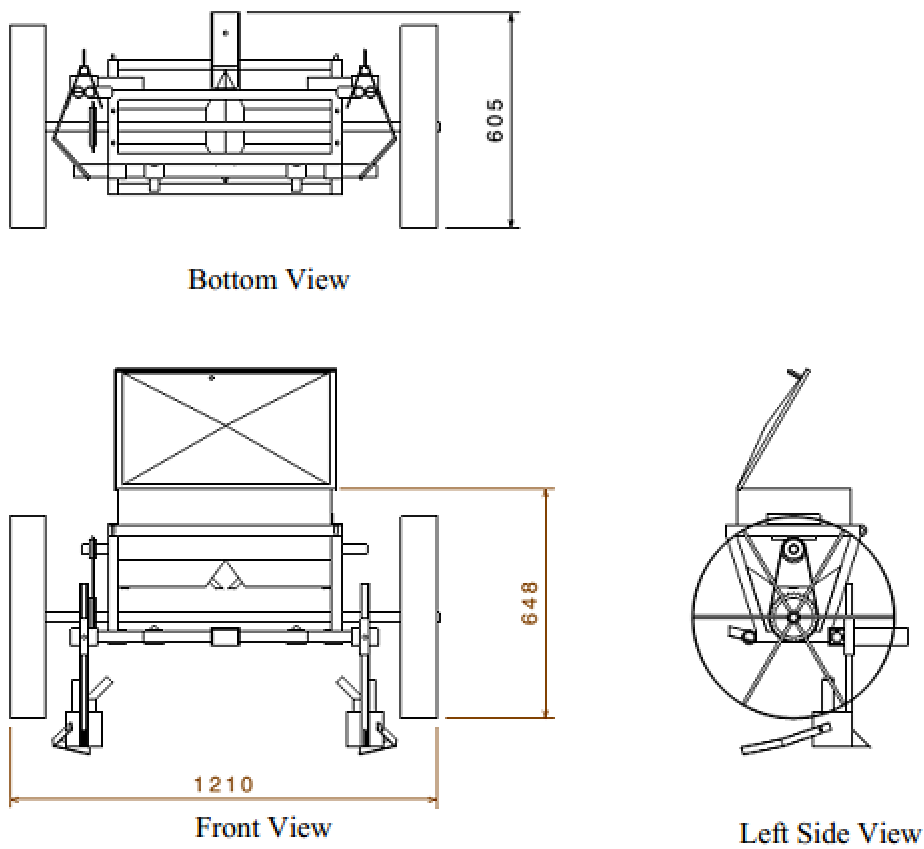


Fig 2. Diagram of the seed planter indicating necessary dimensions (dimensions are in mm).

Based on the research conducted by Mengistu and Kefyalew, the developed prototype was tested at three different working speeds of 1km/hr, 3km/hr, and 5km/hr. According to Mengistu's study, the mean working speed of Ethiopian pair of oxen is between 0.4 and 0.5 m/s (Mengistu, 1999, unpublished) and Kefyalew also reported that the mean working speeds of the camels, oxen and donkeys at 50 kg load were 1.20, 0.59 and 0.52 m/s, respectively (Kefyalew,2014, unpublished). So, the speeds which were selected could incorporate the pull performance capacity of Ethiopian draft animals.

In this design, the maximum forward speed, **5km/hr**, was used in design analysis in order to estimate the maximum power required to drive the machine and to calculate associated forces on the machine due to chain motion, ground reaction, etc. The driving sprocket of the machine is attached to one of the wheels and the driven sprocket is attached to the main shaft on which the metering plates are placed.

3.4.2. Fabrication of the Planter Components

3.4.2.1. Frame

The frame carries the entire components of the machine; as shown in the fig. 3, it had a trapezoidal shaped structure, 380mm by 660 mm at the top and 210 mm by 660 mm at the bottom, constructed from 30 mm by 30 mm square pipe in order to withstand all types of load during operation. The material of the main frame was selected based on achieving a reasonable weight and required strength and reliability and readily available material. The frame was provided with holes on both ends for shaft bearings and support of drive/ground wheels that power to operate the metering devices during laboratory and field performance evaluations. *Mofer* hitching frame material was attached to the main frame, which able to connect beam (*mofer*) and the frame of planter.

The design of the frame was based on the design of components to be mounted on it. The main components which are mounted on frame are hopper, bearings, *mofer* hitching frame and furrow opener. Connections between the frame and other component parts of the planter were made using appropriate sizes of bolts and nuts and arc welding.

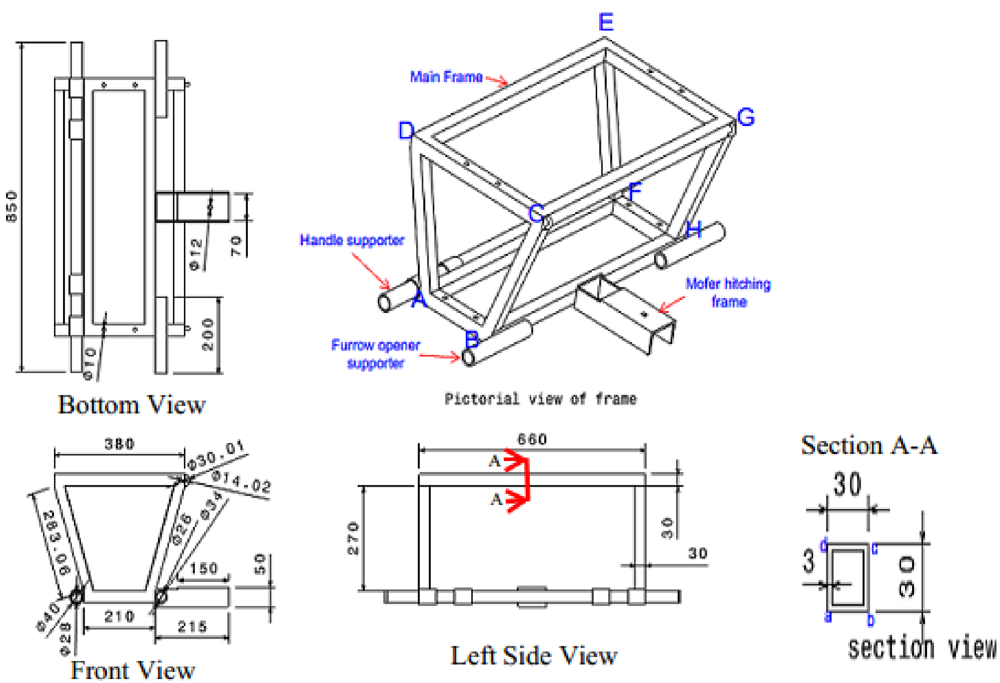


Fig. 3 Frame of the prototype planter (dimensions are in mm).

3.4.2.2. Hopper design

The planter hopper has two compartments, one for seed and the other for fertilizer. The hoppers of the seed and fertilizer were designed to contain 7.5 kg and 7.8 kg respectively, and as shown from fig. 4 below the hoppers have the shape of rectangular cross section at the top and trapezoidal cross section at the bottom to facilitate easy and continuous feeding/flow to the metering devices. The material used for the construction was mild steel sheet metal with thickness of 1.25 mm. The side slope of the hopper at the bottom section must be greater than angle of repose of sorghum which is 33^o (Ashebir, 2015), so in this study 34.29^o side slope to the horizontal was selected to ensure free flow of all seed. The hoppers also have a lid, with a handle on top to ease opening.

The two design factors considered in the determination of hopper capacity are bulk density and seed rate of sorghum, which are 745 kg/m^3 and 15 kg/ha respectively (informal communication with experts). Based on the above stated of rates of seeding, the volume of the hopper was estimated using the equation given by (Olaoye and Bolufawi, 2001), as follows:

$$V_S = \frac{S_r}{n \times \rho_b} \qquad \text{3.4}$$

Where:-

S_r = Seeding rate (kg/ha)

n = Number of refilling per hectare (assume, n=2)

ρ_b = Bulk density of the seeds (kg/ m^3)

V_S = Volume of seeds in the hopper (m^3)

Volume of hopper seed (V_S):-

$$V_S = \frac{15\ \text{Kg/ha}}{2 \times 745\text{Kg/m3}}$$

$V_S = 0.01\ m^3 = 1\times10^4\ cm^3$

Then theoretically the Volume of seed box was calculated by the following formula (Sharma and Mukesh ,2010)

$$V_b = 1.1 \times V_S \ldots\ldots 3.5$$

Where:

V_b = Theoretical Volume of seed box, cm3

V_S = Volume of seeds in the hopper, cm3

Substituting the above mentioned values of V_S and the maximum theoretical volume of seed box would be;

$$V_b = 1.1\times1\times10^4\ cm^3 = 1.1\times10^4\ cm^3$$

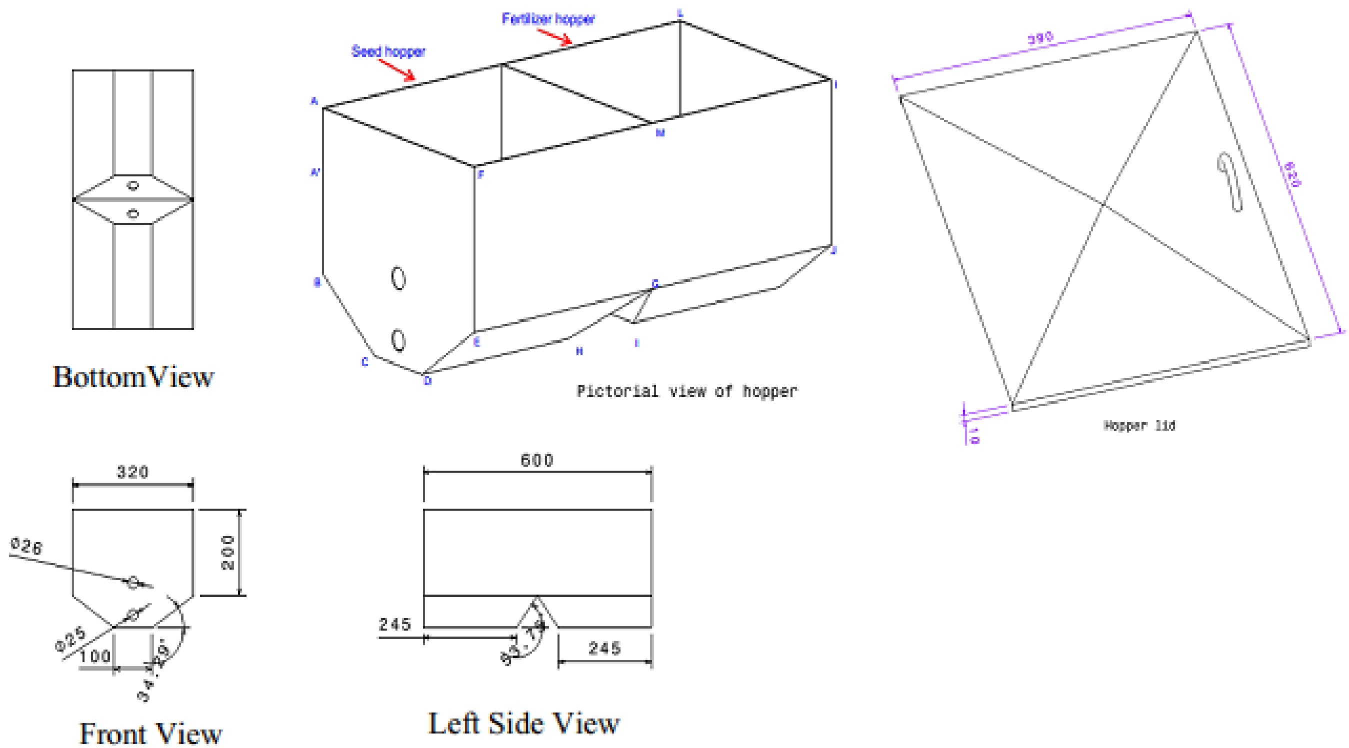


Fig. 4 Hopper and hopper lid of the prototype planter (dimensions are in mm).

We can get the practical dimensions by trial and error methods and as shown from fig.4 the assumed dimensions of the seed hopper were FM = 30cm, CD= 10cm, AB = 20cm, A*B (the working depth of the hopper at full loading) = 15cm, AF = BE = 32cm and vertical distance of BC (h) = 8cm.

Hence, the designed volume of hopper for sorghum seed found using the equation given by (ITSI-SU, 2011)

V_D = ((AB × AF) + ($\frac{1}{2}$ ×X h × (CD +BE))) × FM

Where:

V_D = Designed volume of hopper

V_D = ((15cm × 32cm) + ($\frac{1}{2}$ × 8cm × (10cm + 32cm))) × 30

V_D =1.94 × 10^4 cm^3

Since the designed volume of seed hopper (V_D) is 1.94 × 10^4 cm^3, which is larger than the theoretical volume V_b (1.1×10^4 cm^3). Therefore, the designed dimensions of the hopper are acceptable.

3.4.2.3. Design of seed metering device

Metering mechanism is the heart of sowing machine; it's picks required number of seeds and delivers them into the soil through the tube at required depths created by furrow openers. In the design of seed metering device the size of the seed, the intra row spacing between seed and desired plant populations were considered. The machine had one seed metering plate and six adjustable bolted scoops at each face of the plate, which enabled to plant the seeds in two rows. Proper design of the metering device is an essential element for satisfactory performance of the seed planter. The depth of scoops used for meter the seed was adjustable based on desired rate of planting. The diameter and numbers of scoops were determined on the basis of mean size of sorghum seeds, recommended intra-row spacing of seeds and economical and efficient size (diameter) of driving wheel. Both the wheels and the seed metering plate were designed to give 15cm seed spacing (agronomic recommendation). Since, the depth and orientation of the scoops are adjustable, no need to bother about the depth of scoops but, the size of the scoops was determined based on the value of the average geometrical mean of the sorghum seed, their length(l), width(w), and thickness(t). The largest dimension/diameter for sorghum which measured in laboratory varied between 2.10 and 4.25 mm, so as shown in fig. 5 the scoops to meter sorghum have 8.5 mm diameters because each scoops hold at least two seeds. The ground wheel, through the shafts, provided the desired torque to drive the seed plates through chain-sprocket drive.

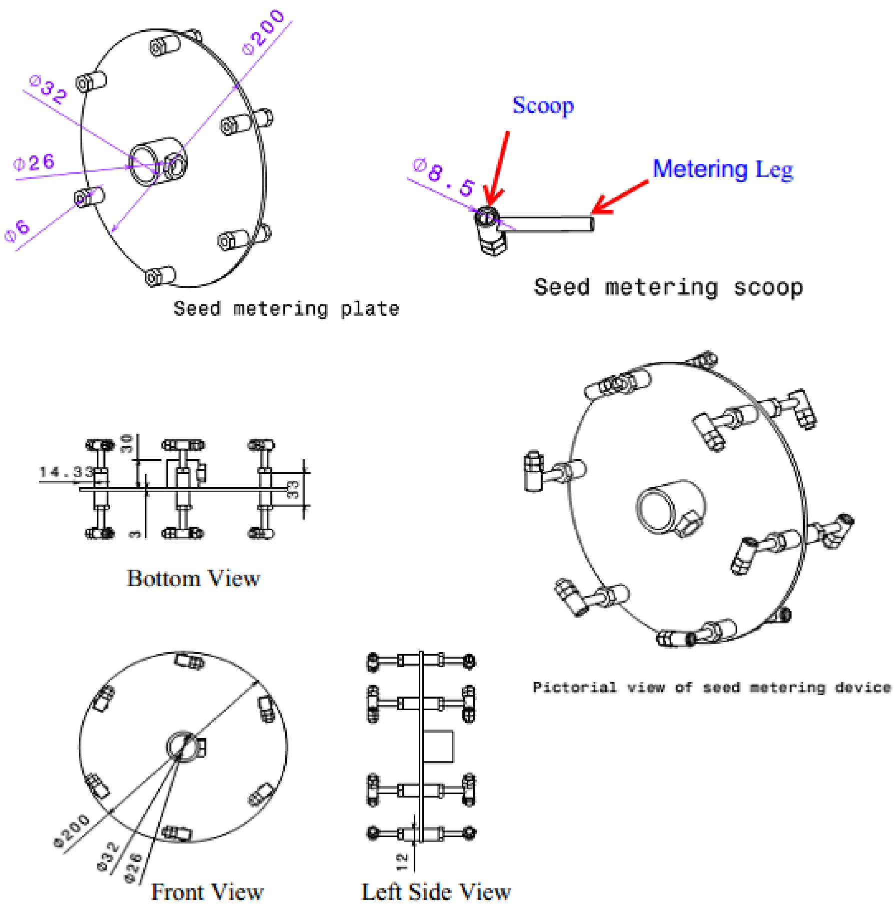


Fig. 5 Seed metering device of the prototype planter (dimensions are in mm).

The number of scoops, m and distance between consecutive scoops, t on the seed metering plate were obtained using the following expressions (Sharma and Mukesh ,2010)

$$m = \frac{\pi \times D_2}{I_{rss}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

$$m = \frac{\pi \times 57\text{cm}}{15\text{cm}} = 11.94 \approx 12$$

To avoid complication the number of scoops found on the plate was 6 but, to get the required number of scoops 2:1 sprocket ratio was used. So, distance between consecutive scoops found t using the following formula (Sharma and Mukesh ,2010)

$$D = \frac{\pi \times D1}{m} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

$D = \frac{\pi \times 20\ \text{cm}}{6}$ = 10.47 cm ≈ 10.5 cm

Where:-

D_1 = Diameter of seed metering plate, (20cm)

D_2 = Diameter of ground wheel, (57cm)

m = Number of scoops on a plate (minimum value)

I_{rss} = Intra-row spacing of seeds, 15cm

D = Distance between consecutive scoops, cm

The calculated number of scoops on metering plates was found to be 12 for sorghum planting at the predetermined seed spacing; but 2:1 driven and driving sprocket ratio was used the number of scoops found on the plate was 6, to get the required number of scoops Similarly, the consecutive distance between scoops on metering plate was determined to be 10.5 cm.

Rate of seed per 100m length row (S_R)

Rate of seed per 100m length row was calculated using the following expression (Sharma and Mukesh ,2010)

$$S_R = \frac{W_S}{N_R} \qquad \text{3.8}$$

But, $N_R = \frac{W_R}{R_S}$ ……3.9

So, $S_R = \frac{W_S}{(W_R/R_S)}$

$$S_R = \frac{15\ \text{Kg}}{(100\ \text{m}/0.7\text{m})}$$

S_R=0.105 Kg/row

S_R=105gm/row

Where:-

W_R = Width of a hectare of land, 100m (assuming the area has a square shape)

` R_S = Row spacing, 70 cm

N_R = Number of rows in a hectare of land for sorghum crop, no

W_S = Weight of seed for a hectare of land, 15 Kg

S_R = Rate of seed per 100 m row, gm/row

Seed rate per revolution of the plate (S_{RPR})

Seed rate per revolution of the plate was calculated using the following expression (Sharma and Mukesh ,2010)

$$S_{RPR} = \frac{\pi \times D1 \times S_R}{100} \qquad \text{3.10}$$

$$S_{RPR} = \frac{\pi \times 0.2\ m \times 105\ gm/row}{100\ m}$$

S_{RPR} =0.66 gm/rev

Where:-

S_{RPR} = Seed rate per revolution of the plate, gm/rev

D_1= Diameter of the seed plate, 0.2m

S_R = Rate of seed per 100m row, gm/row

Mass of seeds per scoop (M_{SPS})

Mass of seeds per scoop was calculated using the following expression (Ashebir, 2015)

$$M_{SPS} = \frac{S_{RPR}}{m} \qquad \text{3.11}$$

$$M_{SPS} = \frac{0.66\ gm/rev}{6\ scoops/rev}$$

M_{SPS} = 0.11gm/scoop

Where:-

M_{SPS} = Mass of seeds per scoop, gm/scoop

m = Number of scoops per a revolution of plate (6 scoops)

S_{RPR} = Seed rate per revolution of the plate, gm/rev

Volume of scoop (V_{SS})

Volume of scoop was calculated using the following expression (Ashebir, 2015)

$$V_{SS} = \frac{M_{SPS}}{\rho_f} \qquad \text{3.12}$$

$$V_{SS} = \frac{0.11\ gm/scoop}{7.45 \times 10^5 gm/m3}$$

$V_{SS} = 1.48 \times 10^{-7}\ m^3$

V_{SS}= 0.15 cm^3

Where: -

ρ_f = Density of sorghum seed, (745 Kg/m^3 = 7.45 X 10^5 gm/m^3)

M_{SPS} = Mass of seeds per scoop, gm/scoop

V_{SS} = Volume of seed scoop, cm^3

Thus the minimum depth of seed scoop to accommodate 0.11gm of sorghum seed during planting sorghum would be found by using the following formula (Sharma and Mukesh ,2010)

$$V_{SS} = \frac{\pi \times D_S{}^2 \times d_s}{4} \qquad \text{3.13}$$

$$0.15cm^3 = \frac{\pi \times (0.85\ \text{cm})^2\ \times\ d_{ds}}{4}$$

d_s = 0.26 cm ≈0.3cm =3 mm

Where: -

V_{SS} = Volume of seed scoop, cm^3

D_S = Diameter of seed scoop, cm

d_{ds} = Design depth of seed scoop, cm

The calculated design depth of scoops were 3mm but, the minimum depth of seed scoop used in this design was 5mm because, the largest dimension of sorghum seed which measured in laboratory used to test the performance of the prototype was 4.25mm.

3.4.2.4. Design of fertilizer metering device

As shown on the fig. 6 the machine had one fertilizer metering plate and six adjustable scoops at each face of the plate were bolted, which used to sow the fertilizers in two row. Proper design of the metering device is an essential element for satisfactory performance of the seed planter. The diameter of the fertilizer plate would be the same as seed plate, hence the number of scoops and distance between consecutive scoops also similar. In addition, like seed metering device the depth of fertilizer metering device also adjustable. But according to the regional Agricultural bureau extension program manual 2006 the recommended DAP (Di Ammonium Phosphate) fertilizer rate for sorghum crop and spacing between rows are 100 Kg/ha and 70 cm respectively, so the size and depth of scoops on the fertilizer plate would be different.

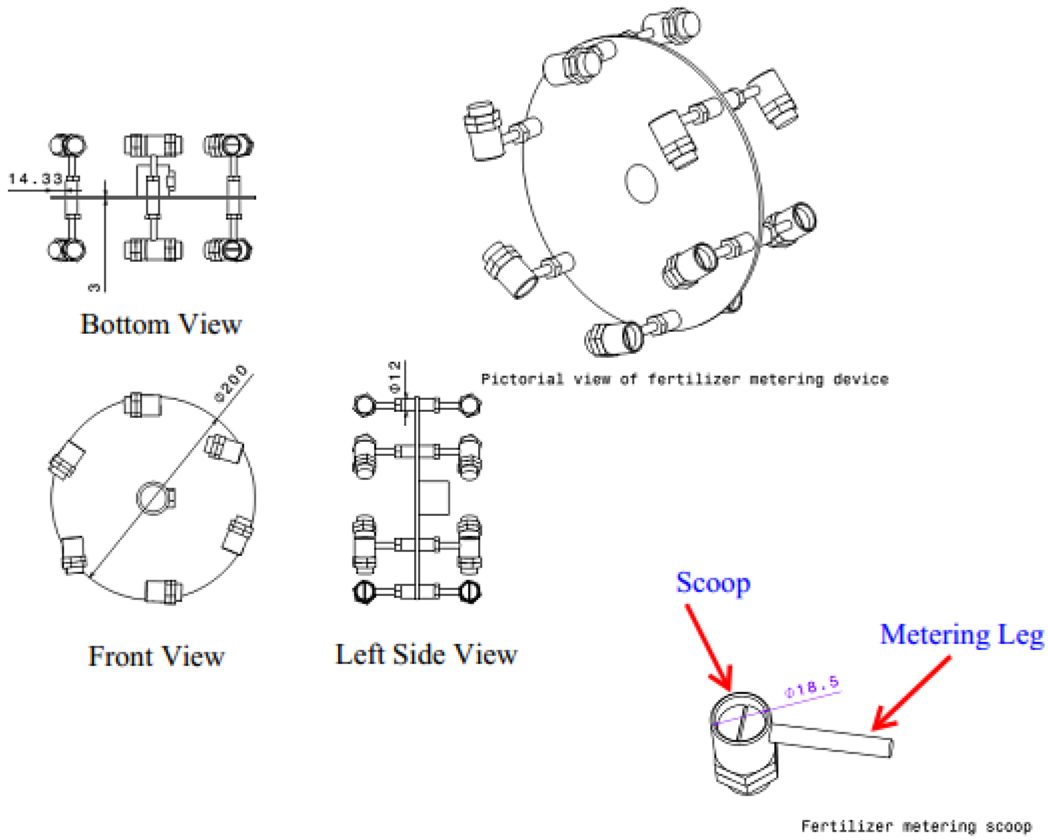


Fig. 6 Fertilizer metering device of the prototype planter (dimensions are in mm).

Rate of fertilizer per 100m length row (F_R)

Rate of fertilizer per 100m length row was calculated using the following expression (Sharma and Mukesh ,2010)

$$F_R = \frac{W_F}{N_R} \qquad \text{.......3.14}$$

$$\text{But,} \quad N_R = \frac{W_R}{R_S} \qquad \text{.......3.15}$$

$$\text{So,} \quad F_R = \frac{W_F}{(W_R/R_S)}$$

$$F_R = \frac{100\ \text{Kg}}{(100/0.7\text{m})}$$

F_R=0.70 Kg/row

F_R=700 gm/row

Where:-

W_R = Width of a hectare of land, 100 m (assuming the area has a square shape)

` R_S = Row spacing, 70 cm

N_R = Number of rows in a hectare of land for sorghum crop, no

W_F = Weight of DAP fertilizer for a hectare of land, 100 Kg

F_R = Rate of fertilizer per 100m row, gm/row

Fertilizer rate per revolution of the plate (F_{RPR})

Fertilizer rate per revolution of the plate was calculated using the following expression (Ashebir, 2015)

$$F_{RPR} = \frac{\pi D1 \times F_R}{100} \quad \text{......3.16}$$

$$F_{RPR} = \frac{\pi \times 0.2\ \text{m} \times 700\ \text{gm/row}}{100\ \text{m}}$$

F_{RPR} = 4.4 gm/rev

Where:-

F_{RPR} = Fertilizer rate per revolution of the plate, gm/rev

D1 = Diameter of the fertilizer plate, 0.2m

F_R = Rate of fertilizer per 100m row, gm/row

Mass of fertilizer per scoop (M_{FPS})

Mass of fertilizer per scoop was calculated using the following expression (Sharma and Mukesh ,2010)

$$M_{FPS} = \frac{F_{RPR}}{m} \quad \text{......3.17}$$

$$M_{FPS} = \frac{4.4\ \text{gm/rev}}{6\ \text{scoops/rev}}$$

M_{FPS} = 0.73 gm/scoop

Where:-

M_{FPS} = Mass of fertilizer per scoop, gm/scoop

m = Number of scoops per a revolution of plate (6 scoops)

F_{RPR}= Fertilizer rate per revolution of the plate, gm/rev

Volume of scoop (V_{FS})

Volume of scoop was calculated using the following expression (Ashebir, 2015)

$$V_{FS} = \frac{M_{FPS}}{\rho_f} \quad \text{.......... 3.18}$$

$$V_{FS} = \frac{0.73\ \text{gm/scoop}}{8.01 \times 10^5 \text{gm}/m^3}$$

$$V_{FS} = 9.11 \times 10^{-7}\ \text{m}^3$$

$$V_{FS} = 0.91 \text{cm}^3$$

Where: -

ρ_f = Density of fertilizer, (801 Kg/m^3 = 8.01×10^5 gm/m^3)

V_{FS} = Volume of fertilizer scoop

Thus the minimum depth of fertilizer scoop to accommodate 0.73gm, of fertilizer during planting sorghum would be:

$$V_{FS} = \frac{\pi \times D_F{}^2 \times d_F}{4} \quad \text{.......... 3.19}$$

$$0.91\ cm^3 = \frac{\pi \times (1.85\ \text{cm})^2 \times d_{dF}}{4}$$

$$d_{dF} = 0.33\ \text{cm} \approx 0.4\ \text{cm} = 4\ \text{mm}$$

Where: -

V_{FS} = Volume of fertilizer scoop

D_F = Diameter of fertilizer scoop

d_{dF} = Depth of fertilizer scoop

Even though the depth of the scoop is adjustable, the minimum depth of fertilizer scoop used in this design was 4 cm to accommodate the required amount of fertilizer

3.4.2.5. Adjustable furrow opener

Furrow opener is generally selected to open the furrow for seed and fertilizer application at desirable depth. Soil type, soil condition, angle of attack and depth of planting should be considered in designing furrow openers. The type of furrow opener used for this design is Shoe type furrow Opener which able to maintain 3.2cm distance between seed and fertilizer because, as shown fig. 7 the center to center distance between the seed and fertilizer pipes is 3.2cm. It used to avoid seed rebounding, facilitate a convenient cut process through the soil and to improve seed placement accuracy (Murray et al., 2006). The wings were welded to the steel shank that was hitched to frame of the planter with bolts and nuts.

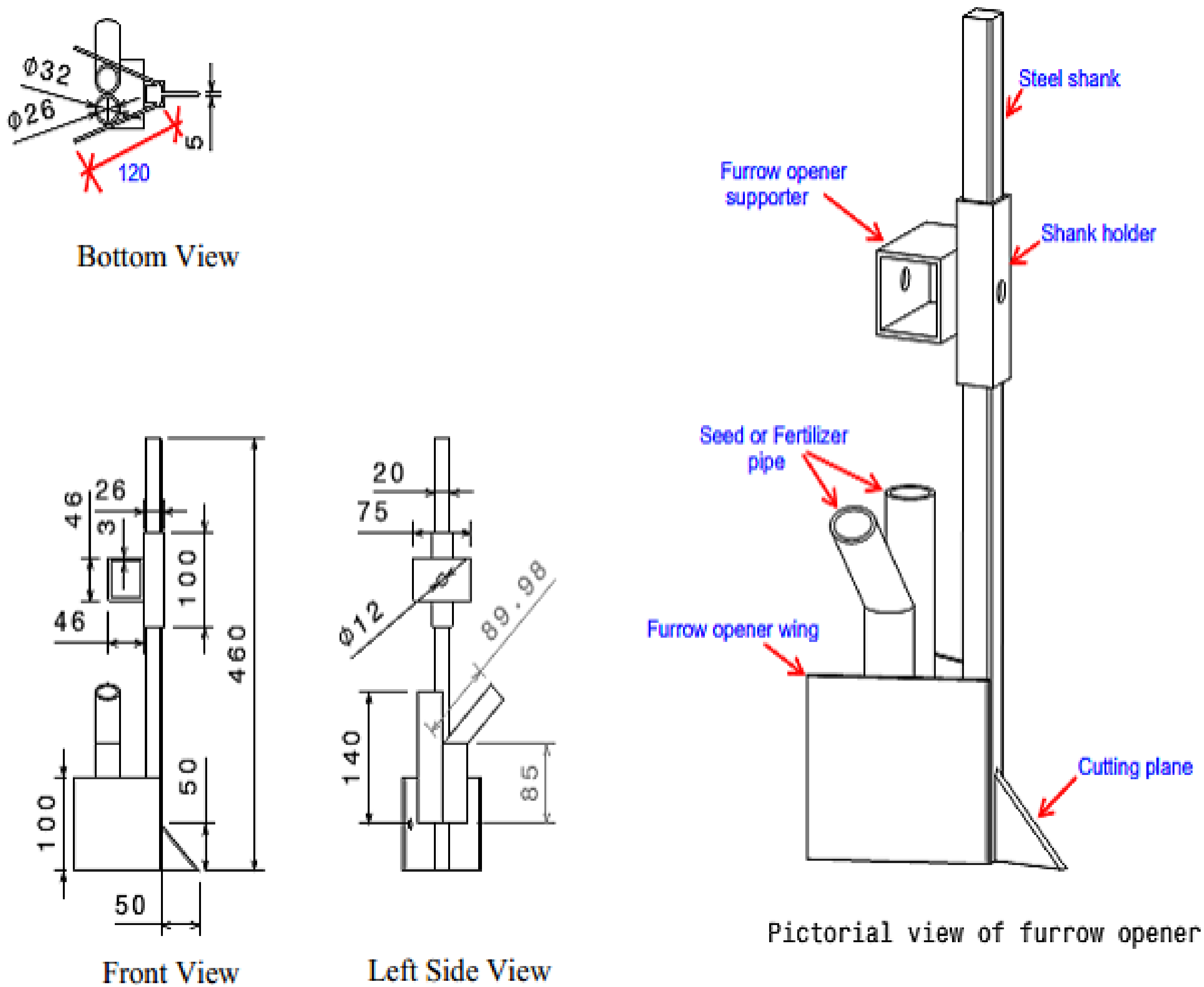


Fig. 7 Adjustable furrow opener of the prototype planter (dimensions are in mm)

3.4.2.6. Furrow covering device

The furrow closer was also designed to be flexible and pivoted on furrow opener wing (see fig.1). As shown below (fig. 8) it was designed to allow for proper covering of the soil over the seeds in the furrows. The material used for the design was mild steel angle iron of 2 mm thickness. These covering devices were fastened to the rear of the wing of furrow openers.

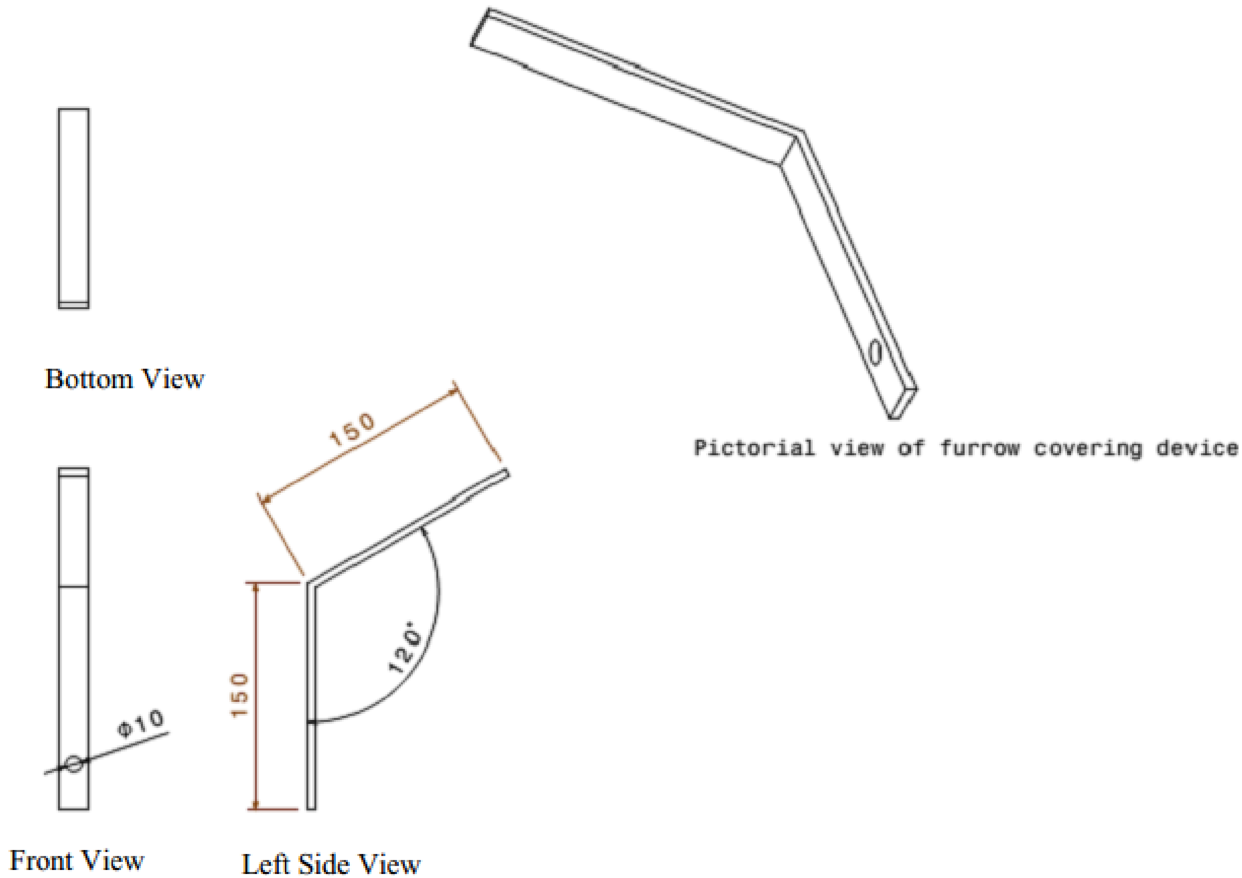


Fig. 8 Furrow covering of the prototype planter (dimensions are in mm)

3.4.2.7. Seed/fertilizer tubes

This was the channel through which seeds or fertilizers are conveyed to the furrow. This may be the collapsible or rigid type. The one for this machine is the rigid type made of plastic tube. Based on the diameter which we want, the tube is directly purchased from the market so, no need to design seed/fertilizer discharge tube.

3.4.2.8. Handle

The handle (fig. 9) is used to provide the push force from a human operator or to support the planter when the planter is pulled by draft animal, to move the planter from point to point during planting operation. It was made of hollow pipes of 19 mm internal diameter, of length 271cm. It was fastened to the frame at the middle of the handle supporter.

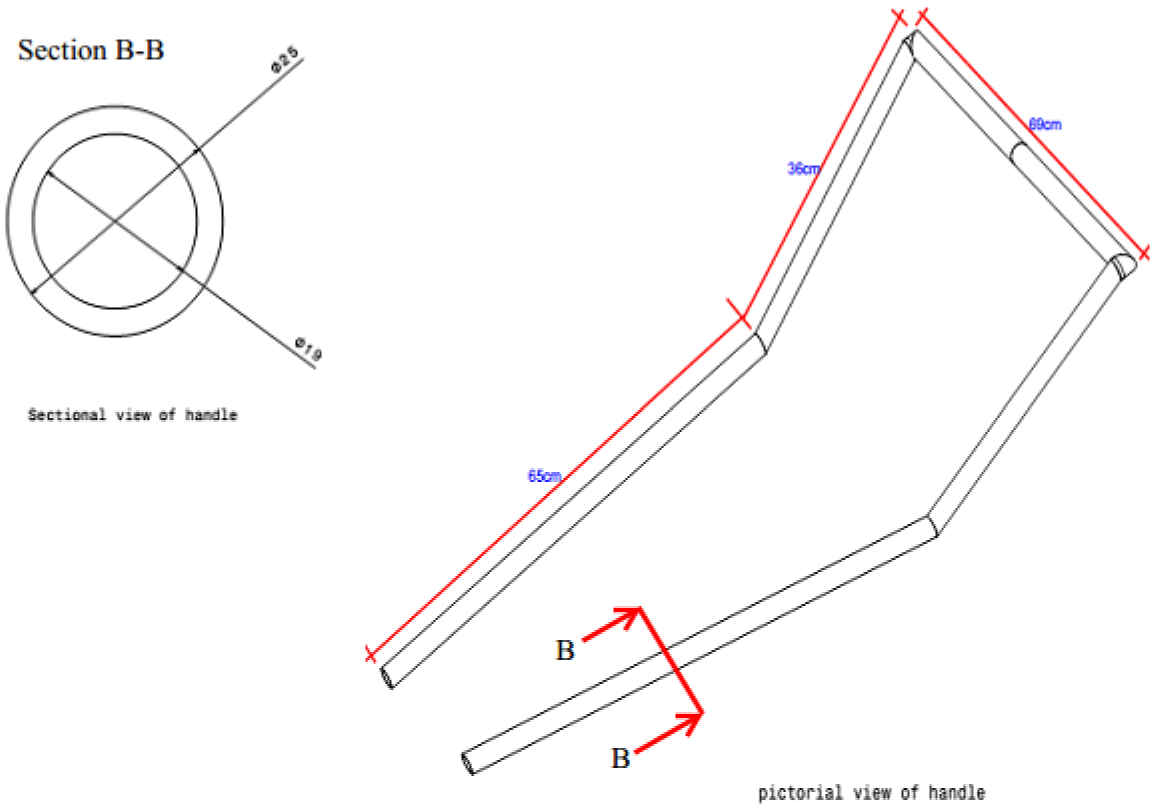


Fig. 9 Handle of the prototype planter

3.4.2.9. Wheel and metering shaft

A shaft is a rotating member, usually of circular cross section, used to transmit power or motion. It provides the axis of rotation, or oscillation, of elements such as gears, pulleys, sprockets etc. The shaft is integral to any mechanical system in which power is transmitted from a prime mover, such as an electric motor or an engine, to other rotating parts of the system. For our design the prime mover was the ground wheel itself.

The prototype had two shafts which were metering and wheel shafts. The wheel shaft used to transmit the rotational movement of ground wheels to the metering shaft through chain and sprocket and the coming power is transmitted to the metering device from the metering shaft.

3.4.2.10. Wheel

The planter has two ground engaging wheels with external diameter of 57 cm. Besides the main function of carrying the whole planter units, the wheels are used to produces the necessary force to drive the seed and fertilizer plates through chain-sprocket drive. In this work, the wheel of the planter was made from 3 mm thick and 100 mm wide sheet metal whose maximum shear strength, τ_{max}, is 80 MPa (see fig. 10) so, the wheels are designed to be a traction wheel to enhance movement on loose soils. Each wheel had six spokes made from reinforcement bars were used to strengthen the wheels with diameter of 8 mm and length of 264 mm, and were welded to the rim and hub at the center of the wheel that served as bushing or shaft bearing, at equal interval.

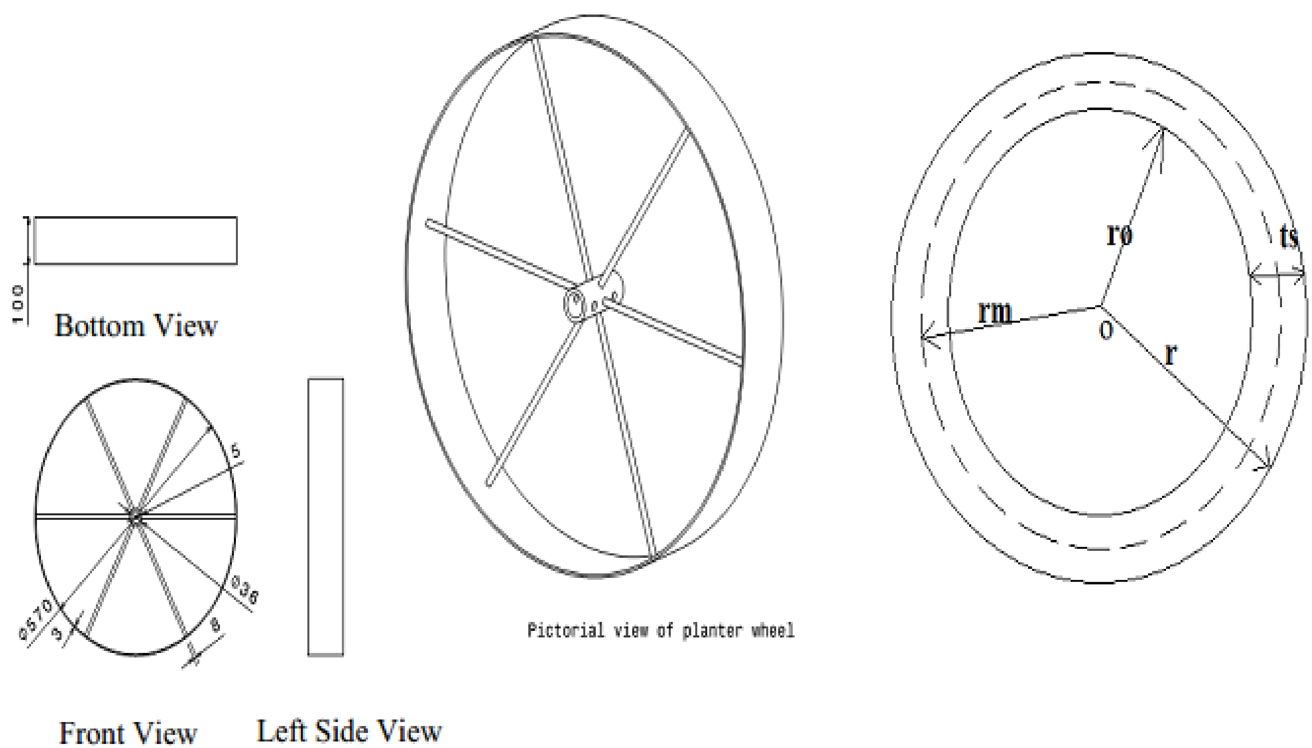


Fig. 10 Wheel of the prototype planter (dimensions are in mm)

3.4.3. Determination the Weight of Component Parts of the Planter

In order to estimate the loads on each and every component parts of the prototype planter, it was necessary to estimate weight of all component parts. Accordingly, the weights of hopper, frame, metering device, furrow openers, furrow covering devices, seed and fertilizer in the hopper were estimated using appropriate equations.

3.4.3.1. Determination of weight of the hopper

Fig. 4 shows the seed and fertilizer hopper used on the planter. The area of the hopper was estimated using the following equations (Math.com, 2012)

$$A_{SHM} = (3\times(AB\times AF)) + (2\times (1/2(BE+CD)\times h)) + (2\times (EF\times FK)) + (2\times (DE\times EJ)) + (2\times (1/2(BE+CD)\times GH)) - (CD\times HI) - (2\times (1/2\times HI\times h)) \quad \ldots 3.20$$

$$A_{SHM} = (3\times(0.2\times 0.32)) + (2(1/2(0.32+0.1)\times 0.08)) + (2\times(0.2\times 0.6)) + (2\times (0.156\times 0.6)) + (2\times (1/2(0.32+0.1)\times 0.168)) - (0.1\times 0.127) - (2\times (1/2(0.127\times 0.08))$$

$$A_{SHM} = 0.701\ m^2$$

The volume of the hopper was estimated using the following equations (ITSI-SU, 2011)

$$V_{HM} = A_{SHM} \times t_{HM} \quad \ldots 3.21$$

But, $t_{HM} = 1.25\ mm = 1.25\times 10^{-3} m$

Hence, $V_{HM} = 0.701 m^2 \times 1.25\times 10^{-3} m$

$V_{HM} = 8.763\times 10^{-4}\ m^3$

The mass of the hopper was estimated using the following equations (ITSI-SU, 2011)

$$M_{HM} = V_{HM} \times \rho_{HM} \quad \ldots 3.22$$

But, $\rho_{HM} = 7850\ Kg/m^3$

Thus, $M_{HM} = 8.763\times 10^{-4}\ m^3 \times 7850\ Kg/m^3$

$M_{HM} = 6.89\ Kg$

The weight of the hopper was estimated using the following equations (Gat, 1988)

$W_{HM} = M_{HM} \times g$……………………………………...…………………..……………………3.23

But, $g = 9.81\ m/s^2$

So, $W_{HM} = 6.89\ Kg \times 9.81\ m/s^2$

$W_{HM} = 67.59\ N$

Where:-

A_{SHM} = Surface area of the hopper material

V_{HM} = Volume of the hopper material

t_{HM} = Thickness of the hopper material

M_{HM} = Mass of the hopper material

ρ_{HM} = Density of the hopper material

W_{HM} = Weight of the hopper material

3.4.3.2. Determination of weight of the hopper lid

Fig. 4 shows the hopper lid used on the planter. The volume of the hopper lid was estimated using the following equations (ITSI-SU, 2011)

$V_{HLM} = A_{SHL} \times t_{HLM}$…………………………………………………...…………………3.24

$A_{SHL} = L_{HL} \times W_{HL}$………………………...……………….……………….3.25

But, $L_{HL} = 640\ mm = 0.64\ m$

$W_{HL} = 390\ mm = 0.39\ m$

So, $A_{SHL} = 0.64\ m \times 0.39\ m$

$A_{SHL} = 0.25\ m^2$

And, $t_{HLM} = 1.25\ mm = 1.25 \times 10^{-3}\ m$

Hence,

$V_{HLM} = 0.25\ m^2 \times 1.25 \times 10^{-3}\ m$

$V_{HLM} = 3.12 \times 10^{-4}\ m^3$

The mass of the hopper lid was estimated using the following equations (ITSI-SU, 2011)

$M_{HLM} = V_{HLM} \times \rho_{HM}$ ……………………………...……………………….....…………………3.26

But, $\rho_{HLM} = 7850\ Kg/m^3$

Thus, $M_{HLM} = 3.12 \times 10^{-4}\ m^3 \times 7850\ Kg/m^3$

$M_{HLM} = 2.45\ Kg$

The weight of the hopper lid was estimated using the following equations (Gat, Uri, 1988)

$W_{HLM} = M_{HLM} \times g$ ………………………………………...………….....…………………3.27

But, $g = 9.81\ m/s^2$

So, $W_{HLM} = 2.451\ Kg \times 9.81\ m/s^2$

$W_{HLM} = 24.03\ N$

Where:-

A_{SHL} = Surface area of the hopper lid

L_{HL} = Length of hopper lid

W_{HL} = Width of hopper lid

V_{HLM} = Volume of the hopper lid material

t_{HLM} = Thickness of the hopper lid material

M_{HLM} = Mass of the hopper lid material

ρ_{HLM} = Density of the hopper lid material

W_{HLM} = Weight of the hopper lid material

3.4.3.3. Determination of weight of the funnel

There are four funnel like structure inside the hoppers to receive the seed or fertilizer from the metering device and transmit it to the delivery hose. Fig. 11 shows the seed and fertilizer funnels used on the planter. The area of the funnels ware estimated using the following equations (Math.com, 2012)

$A_{SSMM} = 2\times(1/2 \times H \times (B_1 + b)) + 2\times (1/2 \times H \times (B_2 + b)) - (2\times (\pi \times D_h^2)/4$ ………….......3.28

$A_{SSMM} = 2\times(1/2 \times 0.09\times(0.085 + 0.02)) + 2\times (1/2 \times 0.09 \times (0.115 + 0.02)) - (2\times (\pi \times 0.026^2)/4$

$A_{SSMM} = 0.021\ m^2$

$A_{CSP} = (\pi \times D^2)/4 - (\pi \times d^2)/4$...……………………………….……………………………..3.29

$A_{CSP} = (\pi \times 0.02^2)/4 – (\pi \times 0.017^2)/4$

$A_{CSP} = 8.72 \times 10^{-5}\ m^2$

The volume of the funnel was estimated using the following equations (ITSI-SU, 2011)

$V_{FM} = A_{SSMM} \times t_{SMM} + A_{CSP} \times L_P$ ……………………………………...………………....3.30

But, $t_{SMM} = 1.25mm = 1.25\times10^{-3}\ m$ and $L_P = 57\ mm = 57\times 10^{-3}\ m$

Hence, $V_{FM} = 0.021\ m^2\times1.25\times10^{-3}\ m + 8.72 \times10^{-5}\ m^2 \times 57 \times 10^{-3}\ m$

$V_{FM} = 3.12\times10^{-5}\ m^3$

The mass of the funnel was estimated using the following equations (ITSI-SU, 2011)

$M_{FM} = V_{FM} \times \rho_{FM}$……………………...………………………...………………………3.31

But, $\rho_{FM} = 7850\ Kg/m^3$

Thus, $M_{FM} = 3.12\times10^{-5}m^3\times 7850\ Kg/m^3$

$M_{FM} = 0.25\ Kg$

The weight of the funnel was estimated using the following equations (Gat, Uri, 1988)

$W_{FM} = M_{FM} \times g$……………………………………………………………………………3.32

But, $g = 9.81\ m/s^2$

So, $W_{FM} = 0.25\ Kg \times 9.81\ m/s^2 \times 4$(four number of funnels)

$W_{FM} = 9.81\ N$

Where:-

A_{SSHM} = Surface area of the sheet metal material

A_{CSP} = Cross sectional area of pipe

D_h = Diameter of hole on sheet metal

D = Outer diameter of pipe

d = Inner diameter of pipe

t_{FM} = Thickness of the funnel material

L_P = Length of the pipe

V_{FM} = Volume of the funnel material

M_{FM} = Mass of the funnel material

ρ_{HM} = Density of the funnel material

W_{FM} = Weight of the funnel material

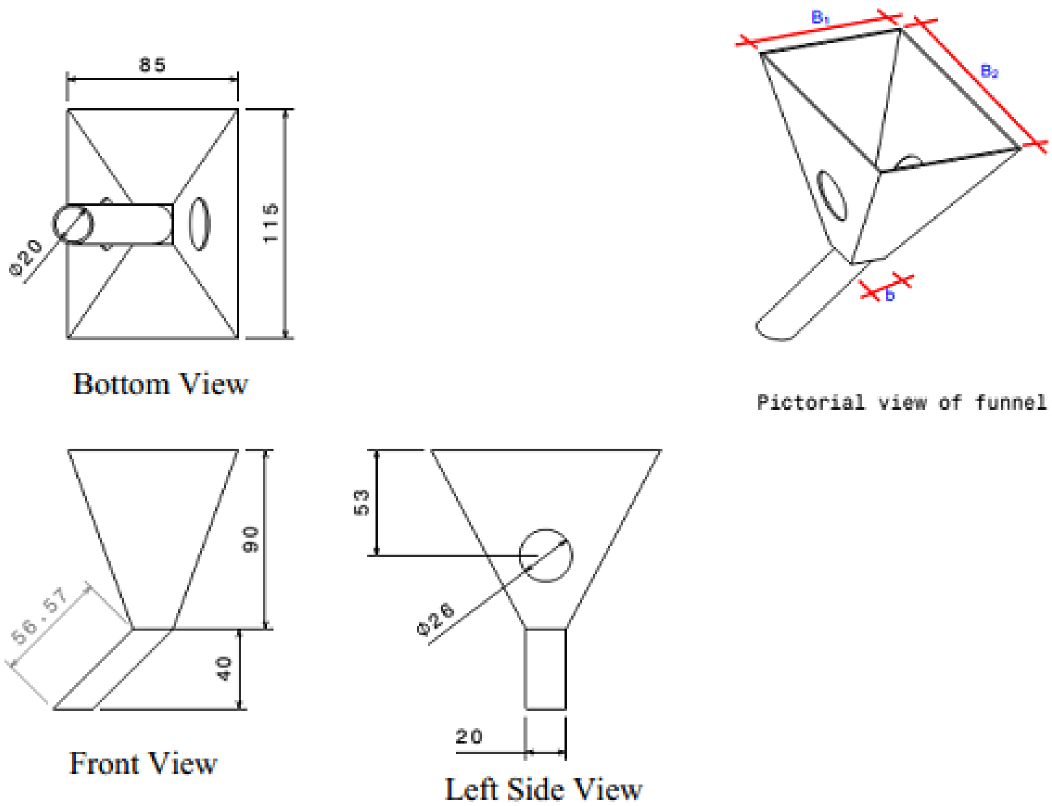


Fig. 11 Funnel of the prototype planter (dimensions are in mm)

3.4.3.4. Determination of the weight of the handle supporter

Fig. 3 shows the handle supporter used on the planter. The area of the handle supporter ware estimated using the following equations (Math.com, 2012)

$A_{CHS} = (\pi \times D^2)/4 - (\pi \times d^2)/4$……………………………..…..……………………………3.33

$A_{CHS} = (\pi \times 0.034^2)/4 - (\pi \times 0.028^2)/4$

$A_{CHS} = 2.92 \times 10^{-4}\, m^2$

The volume of the handle supporter ware estimated using the following equations (ITSI-SU, 2011)

$V_{HS} = A_{CHS} \times L_{HS}$ ……………………………………..………..………………………3.34

But, $L_{HS} = 850\ mm = 0.85\ m$

Hence, $V_{HS} = 2.92 \times 10^{-4} m^2 \times 0.85 m$

$V_{HS} = 2.48 \times 10^{-4}\, m^3$

The mass of the handle supporter ware estimated using the following equations (ITSI-SU, 2011)

$M_{HS} = V_{HS} \times \rho_{HS}$……………………………………..……………………..…………………3.35

But, $\rho_{HS} = 7850\ Kg/m^3$

Thus, $M_{HS} = 2.48 \times 10^{-4}\ m^3 \times 7850\ Kg/m^3$

$M_{HS} = 1.95\ Kg$

The weight of the handle supporter ware estimated using the following equations (Gat, Uri, 1988)

$W_{HS} = M_{HS} \times g$…………………………………………………...………...………………3.36

But, $g = 9.81\ m/s^2$

So, $W_{HS} = 1.95\ Kg \times 9.81 m/s^2$

$W_{FM} = 19.11\ N$

Where:-

A_{CHS} = Cross sectional area of handle support

D = Outer diameter of handle support

d = Inner diameter of handle support

L_P = Length of the handle support

V_{HS} = Volume of the handle support

M_{HS} = Mass of the handle support

ρ_{HS} = Density of the handle support

W_{HS} = Weight of the handle support

3.4.3.5. Determination of the weight of the planter frame

In this design, mild steel rectangular hallow bar of 30 mm x 30 mm x 3 mm was used, so the area of the frame was estimated using the following equations (Math.com, 2012) and Fig. 3 shows the frame used on the planter

$A_{SRHB} = (ab \times bc) - ((ab\text{-}2t_{RHB}) \times (bc\text{-}2t_{RHB}))$………………………………..……………..……3.37

$A_{SRHB} = (0.03\times0.03) - (((0.03 - (2\times0.003)) \times (0.03 - (2\times0.003)))$

$A_{SRHB} = 3.24 \times 10^{-4}\ m^2$

The volume of the frame was estimated using the following equations (ITSI-SU, 2011)

$V_{FM} = A_{SRB} \times L_{RHB}$ ……………………………………..………..…………………………3.38

But, $L_{RHB} = 2AB + 4BC + 2CD + 4DE$ …………………………..………………3.39

$L_{RHB} = (2\times0.21) + (4\times 0.28) + (2\times0.38) + (4\times0.6)$

$L_{RHB} = 4.70$ m

Hence, $V_{FM} = 3.24 \times 10^{-4}\ m^2 \times 4.70$ m

$V_{FM} = 1.52 \times 10^{-3}\ m^3$

The mass of the frame was estimated using the following equations (ITSI-SU, 2011)

$M_{FM} = V_{FM} \times \rho_{FM}$ ………………………………………...………………...………………3.40

But, $\rho_{FM} = 7850\ Kg/m^3$

Thus, $M_{FM} = 1.52 \times 10^{-3}\ m^3 \times 7850\ Kg/m^3$

$M_{FM} = 11.95$ Kg

The weight of the frame was estimated using the following equations (Gat, Uri, 1988)

$W_{FM} = M_{FM} \times g$ ………………………………...……………………………………….....3.41

But, $g = 9.81\ m/s^2$

So, $W_{FM} = 11.95\ Kg \times 9.81\ m/s^2$

$W_{FM} = 117.27$ N

Where:-

A_{SRHB} = Sectional area of rectangular hallow bar of frame material

t_{RHB} = Thickness of rectangular hallow bar

L_{RHB} = Length of rectangular hallow bar

V_{FM} = Volume of frame material

M_{FM} = Mass of frame material

ρ_{FM} = Density of frame material

W_{FM} = Weight of frame material

3.4.3.6. Determination of the weight of the seed metering plate

Fig. 5 shows the seed metering plate used on the planter. The volume of the seed metering plate was estimated using the following equations (ITSI-SU, 2011)

$V_{SMP} = A_{SSMP} \times t_{SMP} + A_{CSSH} \times L_{SH}$……………………………………….……….……3.42

But, $A_{SSMP} = \pi \times (D_2^2 - D_1^2)/4$……………………………………….………..3.43

$A_{SSMP} = \pi \times (0.1^2 - 0.013^2)$

$A_{SSMP} = 0.031\ m^2$

$A_{CSSH} = \pi \times (R_2^2 - R_1^2)$……………………….……………………..3.44

$A_{CSSH} = \pi\ (0.006^2 - 0.003^2)$

$A_{CSSH} = 1.4 \times 10^{-4}\ m^2$

And, $t_{SMP} = 0.003\ m$

$L_{SH} = 0.033\ m$

Hence,

$V_{SMP} = (0.031m^2 \times 0.003m) + (1.4 \times 10^{-4}m^2 \times 0.033m \times 6)$(six number of scoop holder)

$V_{SMP} = 1.21 \times 10^{-4}\ m^3$

The mass of the seed metering plate was estimated using the following equations (ITSI-SU, 2011)

$M_{SMP} = V_{SMP} \times \rho_{SMP}$……………………………………...…………………..……………3.45

But, $\rho_{SMP} = 7850\ Kg/m^3$

Thus, $M_{SMP} = 1.21 \times 10^{-4}m^3 \times 7850\ Kg/m^3$

$M_{SMP} = 0.95\ Kg$

The weight of the seed metering plate was estimated using the following equations (Gat, 1988).

$W_{FM} = M_{SMP} \times g$…………………………………...……………………………..…………3.46

But, $g = 9.81\ m/s^2$

So, $W_{SMP} = 0.95\ Kg \times 9.81\ m/s^2 \times 2$ (two number of metering plate)

$W_{SMP} = 18.59\ N$

Where:-

D_1 and D_2 =Inner and outer radius of seed metering plate

R_1 and R_2 = Inner and outer radius of scoop holder

t_{SMP} = Thickness of seed metering plate

L_{SH} = Length of scoop holder

A_{SSMP} = Surface Area of seed metering plate

ρ_{SMP} = Density of seed metering plate

A_{CSSH} = C/S area of scoop holder

M_{SMP} = Mass of seed metering plate

V_{SMP} = Volume of seed metering plate

W_{SMP} = Weight of seed metering plate

3.4.3.7. Determination of the weight of the seed and fertilizer metering leg

Fig. 5 shows the seed metering leg used on the planter. The volume of the seed metering leg was estimated using the following equations (ITSI-SU, 2011)

$V_{SML} = A_{SML} \times L_{SML}$…………………………………...…….………………………...3.47

But, $A_{SML} = \pi \times r^2$……………………………………………..……………3.48

$A_{SML} = \pi \times (r_2^2 - r_1^2)$……………………………………..…………3.49

$A_{SML} = \pi \times (0.006^2 - 0.003^2)$

$A_{SML} = 8.48 \times 10^{-5}\ m^2$

And, $L_{SML} = 0.033\ m$

Hence, $V_{SML} = 8.48 \times 10^{-5}\ m^2 \times 0.033\ m$

$V_{SML} = 2.80 \times 10^{-6} m^3$

The mass of the seed metering leg was estimated using the following equations (ITSI-SU, 2011)

$M_{SML} = V_{SML} \times \rho_{SML}$ …………………………………..………………..…………………3.50

But, $\rho_{SML} = 7850\ Kg/m^3$

Thus, $M_{SML} = 2.80 \times 10^{-6}\ m^3 \times 7850\ Kg/m^3$

$M_{SML} = 0.022\ Kg$

The weight of the seed metering leg was estimated using the following equations (Gat, Uri, 1988)

$W_{FM} = M_{SML} \times g$…………………………………….....……….……………………………3.51

But, $g = 9.81\ m/s^2$

And, twelve numbers of seed metering leg are used in the design.

So, $W_{SML} = 0.022\ Kg \times 9.81\ m/s^2 \times 12$

$W_{SML} = 2.59\ N$

Where:-

r_1 and r_2 =Outer and inner radius of seed metering leg

L_{SML} = Length of seed metering leg

A_{SML} = Area of seed metering leg

V_{SML} = Volume of seed metering leg

ρ_{SML} = Density of seed metering leg

M_{SML} = Mass of seed metering leg

W_{SML} = Weight of seed metering leg

3.4.3.8. Determination of the weight of the angle iron

Fig. 12 shows the angle iron which is used to connect the hopper to the frame (see fig. 1 how angle iron connect hopper to the frame). The voume of the angle iron was estimated using the following equations (ITSI-SU, 2011)

$V_{AI} = (A_{SAI} \times L_{AI}) - (A_H \times t_H)$……………………………………..…………………….....3.52

But, $A_{SAI} = (AB \times AF) + (ED \times DC)$……………………..…….……………….3.53

$A_{SAI} = (0.03m \times 0.004\ m) + (0.026\ m \times 0.004\ m)$

$A_{SAI} = 2.24 \times 10^{-4}\ m^2$

$A_H = \pi \times D_H^2/4$……………………………………………………………...………………3.54

$A_H = \pi \times 0.010^2/4 \times 2$ (two number of holes)

$A_H = 1.57 \times 10^{-4} m^2$

$L_{AI} = AG = 0.15$ m and $t_H = 4$ mm = 0.004 m

Hence, $V_{AI} = (2.24 \times 10^{-4}\, m^2 \times 0.15\, m) - (1.57 \times 10^{-4}\, m^2 \times 0.004\, m)$

$V_{AI} = 3.30 \times 10^{-5}\, m^3$

The mass of the angle iron was estimated using the following equations (ITSI-SU, 2011)

$M_{AI} = V_{AR} \times \rho_{AI}$…………………………………………………………………….…………3.55

But, $\rho_{AI} = 7850$ Kg/m^3

Thus, $M_{AI} = 3.30 \times 10^{-5}\, m^3 \times 7850$ Kg/m^3

$M_{AI} = 0.26$ Kg

The weight of the angle iron was estimated using the following equations (Gat, Uri, 1988)

$W_{AI} = M_{AI} \times g$………………………………………………………………………….....3.56

But, $g = 9.81 m/s^2$

So, $W_{AI} = 0.26$ Kg $\times$ 9.81 m/s^2 $\times 2$(two number of angle iron)

$W_{AI} = 5.12$ N

Where:-

A_{SAI} = surface area of angle iron

A_H = Area of hole

D = Diameter of hole

t_H = Thickness of angle iron

L_{AI} = Length of angle iron

V_{AI} = Volume of angle iron

M_{AI} = Mass of angle iron

ρ_{AI} = Density of angle iron

W_{AI} = Weight of angle iron

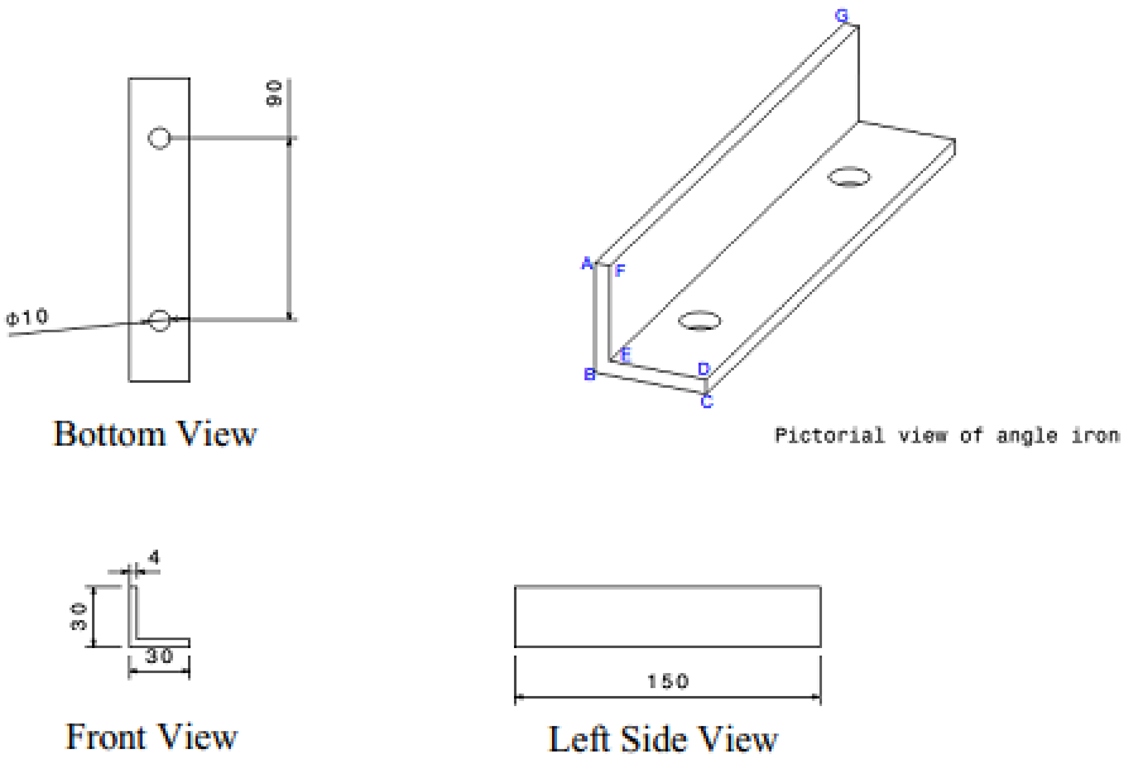


Fig.12. Angle iron (dimensions are in mm)

3.4.3.9. Determination of the weight of furrow opener

Fig.7 shows the furrow opener used on the planter. The area of the furrow opener was estimated using the following equations (Math.com, 2012)

$A_{CSSS} = L_{SS} \times W_{SS}$……………………………...……………………...………………3.57

$A_{CSSS} = (0.02\ m \times 0.02\ m)$

$A_{CSSS} = 4 \times 10^{-4}\ m^2$

$A_{CSSSH} = L_{OSSH} \times W_{OSSH} - L_{ISSH} \times W_{ISSH}$……………………………………..……………...3.58

$A_{CSSSH} = (0.026\ m \times 0.026\ m) - (0.02\ m \times 0.02\ m)$

$A_{CSSSH} = 2.76 \times 10^{-4}\ m^2$

$A_{CSFOS} = L_{OFOS} \times W_{OFOS} - L_{IFOS} \times W_{IFOS}$………………………………………………………3.59

A_{CSFOS} = (0.04 m × 0.04 m) – (0.034 m × 0.034 m)

$A_{CSFOS} = 4.44 \times 10^{-4}\ m^2$

$A_{SSMW} = L_{SMW} \times W_{SMW}$……………………………………………………………..………3.60

$A_{SSMW} = 0.12\ m \times 0.1m$

$A_{SSMW} = 0.012m^2$

$A_{CP} = ½ \times L_{CP} \times W_{CP}$………………………………………………...………..…………3.61

$A_{CP} = ½ \times 0.05m \times 0.05m$

$A_{CP} = 1.25 \times 10^{-3} m^2$

$A_{CSP} = (\pi \times D^2)/4 – (\pi \times d^2)/4$ ………………………………………………...…..……………3.62

$A_{CSP} = (\pi \times 0.032m^2)/4 – (\pi \times 0.026m^2)/4$

$A_{CSP} = 2.73 \times 10^{-4} m^2$

The volume of the furrow opener was estimated using the following equations (ITSI-SU, 2011)

$V_{FM} = A_{CSSS} \times L_{SS} + A_{CSSSH} \times L_{SSH} + A_{CSFOS} \times L_{FOS} + A_{SSMW} \times t_{MW} + A_{CP} \times t_{CP} + A_{CSP} \times L_P$…….3.63

But,

L_{SS} = 460mm = 0.46m

L_{SSH} = 100mm = 0.1m

L_{FOS} = 75mm = 0.075m

$t_{MW} = 2mm = 2 \times 10^{-3} m$

$t_{CP} = 5mm = 5 \times 10^{-3} m$

L_P = 310mm = 0.31m (N.B it includes both seed and fertilizer pipe)

Hence,

$$V_{FO} = 4 \times 10^{-4}\ m^2 \times 0.46\ m + 2.76 \times 10^{-4}\ m^2 \times 0.1m + 4.44 \times 10^{-4} m^2 \times 0.075m + 0.012m^2 \times 2 \times 10^{-3} m + 1.25 \times 10^{-3}\ m^2 \times 5 \times 10^{-3}\ m + 2.73 \times 10^{-4}\ m^2 \times 0.31\ m$$

$V_{FO} = 3.60 \times 10^{-4}\ m^3$

The mass of the furrow opener was estimated using the following equations (ITSI-SU, 2011)

$M_{FO} = V_{FM} \times \rho_{FM}$……………………………………………………...……..……………3.64

But, $\rho_{FM} = 7850\ Kg/m^3$

Thus, $M_{FO} = 3.60\times10^{-4}\ m^3 \times 7850\ Kg/m^3$

$M_{FO} = 2.824\ Kg$

The weight of the furrow opener was estimated using the following equations (Gat, Uri, 1988)

$W_{FO} = M_{FO} \times g$…………………………………………..…………………………..…….3.65

But, $g = 9.81\ m/s^2$

So, $W_{FO} = = 2.824\ Kg \times 9.81 m/s^2 \times 2$(two number of furrow openers)

$W_{F0} = 55.41\ N$

Where,

A_{CSSS} = C/s area of steel shank

W_{SS} =Width of steel shank

L_{OSSH} = Outer length of steel shank holder

W_{OSSH} = Outer width of steel shank holder

L_{ISSH} = Inner length of steel shank holder

W_{ISSH} = Inner length of steel shank holder

A_{CSFOS} = C/s area of furrow opener supporter

L_{OFOS} = Outer length of furrow opener supporter

W_{OFOS} = Outer width of furrow opener supporter

A_{CP} = Area of cutting plate

L_{IFOS} = Inner length of furrow opener supporter

W_{IFOS} = Inner length of furrow opener supporter

A_{SSMW} = Surface area of sheet metal wing

L_{SMW} = Length of sheet metal wing

L_{SS}= Length of steel shank

A_{CSSSH} =C/s area of steel shank holder

W_{SMW} = Width of sheet metal wing

L_{CP} = Length cutting plate

W_{CP} = Width cutting plate

A_{CSP} = Cross sectional area of pipe

D = Outer diameter of pipe

d = Inner diameter of pipe

L_{SS} = Length of steel shank

L_{SSH} = Length of steel shank holder

L_{FOS} = Length of furrow opener supporter

t_{MW} = Thickness of wing material

t_{CP} = Thickness of cutting plate

L_P = Tength of pipe

V_{FO} = Volume of the furrow opener

M_{FO} = Mass of the furrow opener

ρ_{HO} = Density of the furrow opener

W_{FO} = Weight of the furrow opener

3.4.3.10. Determination of the weight of furrow covering device

Fig. 8 shows the furrow covering device used on the planter. The volume of the furrow covering device was estimated using the following equations (ITSI-SU, 2011)

$V_{FCD} = (A_{SFCD} \times L_{FCD}) - (A_h \times t_h)$……………………..……………………..…………3.66

The area of the furrow covering device was estimated using the following equations (Math.com, 2012)

$A_{SFCD} = t_{FCD} \times W_{FCD}$…………………………………………………………………......3.67

$A_h = \pi \times D_h^2/4$………………………………………..………………………………...3.68

But, $t_{FCD} = t_h = 5\ mm = 0.005\ m$

$W_{FCD} = 20\ mm = 0.02\ m$

$D_h = 10\ mm = 0.01m$

$L_{FCD} = 300\ mm = 0.3\ m$

So, $A_{SFCD} = 0.005\ m \times 0.02\ m$

$A_{SFCD} = 1 \times 10^{-4}\ m^2$

And, $A_h = \pi \times (0.01m)^2/4$

$A_h = 7.85 \times 10^{-5}\ m^2$

Hence,

$V_{FCD} = (1 \times 10^{-4}\ m^2 \times 0.3\ m) - (7.85 \times 10^{-5}\ m^2 \times 0.005\ m)$

$V_{FCD} = 2.96 \times 10^{-5}\ m^3$

The mass of the furrow covering device was estimated using the following equations (ITSI-SU, 2011)

$M_{FCD} = V_{FCD} \times \rho_{FCD}$……………………………………...…………...…………………3.69

But, $\rho_{FCD} = 7850\ Kg/m^3$

Thus, $M_{FCD} = 2.96 \times 10^{-5}\ m^3 \times 7850\ Kg/m^3$

$M_{FCD} = 0.23\ Kg$

The weight of the furrow covering device was estimated using the following equations (Gat, Uri, 1988)

$W_{FCD} = M_{FCD} \times g$……………………………………………...……………………..……3.70

But, $g = 9.81\ m/s^2$

So, $W_{FCD} = 0.23\ Kg \times 9.81\ m/s^2 \times 2$ (two number of furrow covering device)

$W_{FCD} = 4.56\ N$

Where:-

A_{SFCD} = Surface area of furrow covering device

W_{FCD} = Height of furrow covering device

L_{FCD} = Length of furrow covering device

$_{FCD}$= Width of furrow covering device

t_{FCD} = Thickness of furrow covering device

V_{FCD} = Volume of furrow covering device

M_{FCD} = Mass of furrow covering device

ρ_{FCD} = Density of furrow covering device

W_{FCD} = Weight of furrow covering device

3.4.3.11. The weight of *mofer* hitching frame material

Fig.3 shows the *mofer* hitching frame which used to attach the prototype planter to the draft power source. The volume of the *mofer* hitching frame was estimated using the following equations (ITSI-SU, 2011)

$V_{MHM} = (A_{SMHM} \times L_{MHM}) – (A_H \times t_H)$…………………………………………..….…………3.71

The area of the *mofer* hitching frame was estimated using the following equations (Math.com, 2012)

$A_{SMHM} = (0.05\ m \times 0.08\ m) - (0.045\ m \times 0.07 m)$

$A_{SMHM} = 8.5 \times 10^{-4}\ m^2$

$A_H = \pi \times D_H^2/4$…………………………………………….………………..….3.72

$A_H = \pi \times 0.012^2/4$

$A_H = 1.13 \times 10^{-4}\ m^2$

And, $L_{AI} = 0.21\ m$

t_H= 5mm = 0.005 m

Hence, $V_{MHM} = (8.5 \times 10^{-4}\ m^2 \times 0.21\ m) – (1.13 \times 10^{-4}\ m^2 \times 0.005\ m)$

$V_{MHM} = 1.78 \times 10^{-4}\ m^3$

The mass of the *mofer* hitching frame was estimated using the following equations (ITSI-SU, 2011)

$M_{MHM} = V_{MHM} \times \rho_{AI}$……………………………………..…………..………………………3.73

But, $\rho_{MHM} = 7850\ Kg/m^3$

Thus, $M_{MHM} = 1.78 \times 10^{-4}\ m^3 \times 7850\ Kg/m^3$

$M_{MHM} = 1.4\ Kg$

The weight of the *mofer* hitching frame was estimated using the following equations (Gat, Uri, 1988)

$W_{MHM} = M_{MHM} \times g$……………………………………..…………..………………………3.74

But, $g = 9.81\ m/s^2$

So, $W_{MHM} = 1.4\ Kg \times 9.81\ m/s^2$

$W_{MHM} = 13.70\ N$

Where:-

A_{SMHM} = Surface area of *mofer* hitching material

A_H = Area of hole

D = Diameter of hole

t_H = Thickness of *mofer* hitching material

L_{MHM} = Length of *mofer* hitching material

V_{MHM} = Volume of *mofer* hitching material

M_{MHM} = Mass of *mofer* hitching material

ρ_{MHM} = Density of *mofer* hitching material

W_{MHM} = Weight of *mofer* hitching material

3.4.3.12. Determination of the weight of handle

Fig. 9 shows the handle which used to support the planter during operation. The volume of the handle was estimated using the following equations (ITSI-SU, 2011)

$V_H = (A_{CSH} \times L_H)$………………………………………..….…………………………...3.75

The area of the handle was estimated using the following equations (Math.com, 2012)

But, $A_{CSH} = \pi \times (D_2^2 - D_1^2)/4$…………………………………..…...………..………3.76

$A_{CSH} = \pi \times (0.025m^2 - 0.019^2)/4$

$A_{CSH} = 2.07 \times 10^{-4}\ m^2$

And, $L_H = 2.71m$

Hence,

$V_H = 2.07 \times 10^{-4}m^2 \times 2.71m$

$V_H = 5.62 \times 10^{-4}m^3$

The mass of the handle was estimated using the following equations (ITSI-SU, 2011)

$$M_H = V_H \times \rho_{AI} \qquad \text{...3.77}$$

But, $\rho_H = 7850\ Kg/m^3$

Thus, $M_H = 5.62 \times 10^{-4}\ m^3 \times 7850\ Kg/m^3$

$M_H = 4.41\ Kg$

The weight of the handle was estimated using the following equations (Gat, Uri, 1988)

$$W_H = M_H \times g \qquad \text{...3.78}$$

But, $g = 9.81m/s^2$

So, $W_H = 4.41\ Kg \times 9.81m/s^2$

$W_H = 43.27\ N$

Where:-

D_1 and D_2 = Inner and outer diameter of handle respectively	V_H = Volume of handle
	M_H = Mass of handle
A_{CSH} = Cross sectional area of handle	ρ_H = Density of handle
L_H = Length of handle	W_H = Weight of handle

3.4.3.13. Determination of the weight of seed metering shaft

Seed metering shaft is used to receive the rotational movement of wheel shaft through chain and rotate both seed and fertilizer metering device. The volume of the seed metering shaft was estimated using the following equations (ITSI-SU, 2011).

$$V_{MS} = (A_{CSMS} \times L_{MS}) \qquad \text{...3.79}$$

The area of the seed metering shaft was estimated using the following equations (Math.com, 2012).

$$A_{CSMS} = \pi \times (D^2)/4 \qquad \text{3.80}$$

Assume the minimum diameter for metering shaft that is D = 20mm = 0.02m

$A_{CSMS} = \pi \times (0.02^2)/4$

$A_{CSMS} = 3.14 \times 10^{-4}\ m^2$

And, $L_{MS} = 0.805$ m

Hence,

$V_{MS} = 3.14 \times 10^{-4}\ m^2 \times 0.805$ m

$V_{MS} = 2.53 \times 10^{-4}\ m^3$

The mass of the seed metering shaft was estimated using the following equations (ITSI-SU, 2011)

$$M_{MS} = V_{MS} \times \rho_{MS} \qquad \text{3.81}$$

But, $\rho_{MS} = 7850\ Kg/m^3$

Thus, $M_{MS} = 2.53 \times 10^{-4} m^3 \times 7850\ Kg/m^3$

$M_{MS} = 1.98$ Kg

The weight of the seed metering shaft was estimated using the following equations (Gat, Uri, 1988).

$$W_{HS} = M_{MS} \times g \qquad \text{3.82}$$

But, $g = 9.81\ m/s^2$

So, $W_{MS} = 1.98\ Kg \times 9.81\ m/s^2$

$W_{MS} = 19.42$ N

Where:-

A_{CSMS} = Cross sectional area of metering shaft

D = Diameter of metering shaft

L_{MS} = Length of metering shaft

V_{MS} = Volume of metering shaft

M_{MS} = Mass of metering shaft

ρ_{MS} = Density of metering shaft

W_{MS} = Weight of metering shaft

3.4.3.14. Determination of the weight of grain

The weight of the seeds in the hoppers was estimated from the net volume of the hopper and bulk density of the seeds. The net volume of hopper is the maximum volume of hopper which able to hold the seed at full load, and the mass of grain was estimated using the following equations (ITSI-SU, 2011)

$M_G = V_S \times \rho_G$……………………………………..…………………………………..…………3.83

But, $Vs = \frac{\mathrm{Sr}}{\mathrm{n} \times \rho_G}$ (see equation 5)

$\rho_G = 745 Kg/m3$

$$Vs = \frac{15\mathrm{Kg/ha}}{2 \times 745 Kg/m3}$$

$V_S = 0.01m^3 = 1\times10^4 cm^3$

Hence,

$M_G = 0.01m^3 \times 745 Kg/m3$

$M_G = 7.45$ Kg

The weight of grain was estimated using the following equations (Gat, Uri, 1988)

$W_G = M_G \times g$……………………………………..…………………..……………………….3.84

But, $g = 9.81 m/s^2$

So, $W_G = 7.45 \text{ Kg} \times 9.81 m/s^2$

$W_G = 73.08$ N

Where:-

V_S = Volume of seed/ grain

S_R = Seed rate

ρ_b = Bulk density of grain

n = Number of refill

M_G = Mass of grain

ρ_G = Density of grain

W_G = Weight of grain

3.4.3.15. Determination of the weight of fertilizer

The weight of the fertilizer in the hoppers was estimated from the net volume of the hopper and bulk density of the fertilizer. The net volume of hopper is the maximum volume of hopper which able to hold the fertilizer at full load, and the mass of fertilizer was estimated using the following equations (ITSI-SU, 2011)

$M_F = V_F \times \rho_F$……………………………...…………………..………………………3.85

But, $V_F = \frac{FR}{n \times \rho F}$(see equation 5)

$\rho_F = 801Kg/m3$

$$V_F = \frac{100Kg/ha}{13 \times 801Kg/m3}$$

$V_F = 0.01m^3 = 1\times10^4cm^3$

Hence,

$M_F = 0.01m^3 \times 801\ Kg/m3$

$M_F = 7.69$ Kg

The weight of fertilizer was estimated using the following equations (Gat, Uri, 1988)

$W_F = M_F \times g$……………………………...……………………………...…………….3.86

But, $g = 9.81m/s^2$

So,

$W_F = 7.69\ Kg \times 9.81m/s^2$

$W_F = 75.46$ N

Where:-

V_F = Volume of fertilizer

S_R = Seed rate

N = Number of refill

M_F = Mass of fertilizer

ρ_F = Density of fertilizer

W_G = Weight of fertilizer

3.4.3.16. Determination of the weight of bearing

In this design four bearing are used to support metering and wheel shaft and also to reduce friction and stress between moving parts. The weight of bearing was estimated using the following equations (Gat, Uri, 1988)

$W_B = M_B \times g$……………………………………...…………………………………...3.87

But, M_B = 0.74 Kg (measured value of single bearing)

$g = 9.81\ m/s^2$

Hence, $W_B = 4 \times M_B \times g$ (because four bearings were used in the design)

$W_B = 4 \times 0.74\ Kg \times 9.81\ m/s^2$

$W_B = 29.04\ N$

Where:-

M_B = Mass of bearing

W_B = Weight of bearing

The total weight the prototype planter including seeds, fertilizer, *mofer* and bearing was estimated to be 578.05 N. Allowing 2% margins for the weights of welding bolts, nuts, plastic tube, etc. the total weight was found to be 589.61 N ≈ 590 N.

3.4.4. Drive wheel design

3.4.4.1. Wheel strength

The formula used in the analysis was the one that estimates the shear amount in "welded closed thin wall, t<<<d", as dictated by (Richard et.al, 2011). And the maximum shear strength of the wheel is τ_{max},= 80 MPa.

I. Estimation of the force required to drive the planter (Sharma and Mukesh ,2010)

$f_f = (C_R + i) \times m_{we}$ ……………………………………….…………………………3.88

But, $C_R = \sqrt{\frac{Z}{W_d}}$

So, $f_f = (\sqrt{\frac{Z}{W_d}} + i) \times m_{we}$

$$f_f = \left(\sqrt{\frac{3\text{cm}}{57\text{cm}}} + 0.05\right) \times 295$$

$f_f = 82.43$ N

Where:-

f_f = Force required to drive the planter, N

C_R = Coefficient of rolling resistance

Z = Maximum tolerable wheel sinkage depth, let Z=3cm

w_d = Wheel diameter, 57cm

m_{we} = Machine weight on each wheel, 590/2 = 295N

i = Gradient of the ground, let i=5%

II. Torque on the ground wheel (Sharma and Mukesh ,2010)

$T = f_f \times \left(\frac{w_d}{2}\right)$……………………………………………………………………..………3.89

$$T = 82.43 \text{ N} \times \left(\frac{0.57\ m}{2}\right)$$

$T = 23.49$ Nm

Where:-

T = Torque on the ground wheel, Nm

III. Power requirement of the planter (Sharma and Mukesh, 2010)

$P = T \times N_w$……………………..…………………………………………………………..………3.90

P= 23.49 Nm × ((46.54 × 2π)/60)

P= 114.48 w

P= 0.115 Kw

Where:-

` P = Power requirement of the planter, kW

N_w= Wheel revolution,5Km/hr = 0.776 rev/sec = 46.54RPM

IV. Shear stress on the wheel (Sharma and Mukesh, 2010)

$$\tau = \frac{\mathrm{T}}{2A_m \times t_s} \quad \text{..........} 3.91$$

but, $A_m = \pi rm^2$ and $rm = r - 0.5ts$ (refer figure 10)

Hence, $\tau = \frac{\mathrm{T}}{2(\pi[\mathrm{r} - 0.5t_s]^{\,2})\, t_s}$

$$\tau = \frac{23.49 \text{ Nm}}{2(\pi[0.285 \text{ m} - (0.5 \times 0.003\text{m})]^{\,2} 0.003\, m}$$

$\tau = 15505.14$ Pa

$\tau = 15.51$ KPa

Where:-

T = The torque produced by the wheel, 23.49Nm

A_m = The area of the wheel calculated based on the median diameter of the wheel

R = The outer radius of the wheel, 0.285m

r_o= The inner radius of the wheel, 0.282m

r_m = The median radius of the wheel, 0.2835m

t_s= The thickness of the wall/wheel, 0.003m

τ = Shear stress on the wheel, Kpa

Comparing this shear stress with the maximum allowable shear stress of the metal, $\tau \ll \tau_{max}$,, 80 MPa, which tells us the wheel is safe for operation.

3.4.4.2. Estimation of wheel width

According to Hertz (1881), when two cylindrical objects of length L and diameters d_1 and d_2 contact, a narrow rectangle of width 2b and length L is created. The stress created has an elliptical distribution across the contact zone (see fig.13). The half width and the pressure are given by the equations,

$$b = \sqrt{\left(\frac{2\mathrm{F}}{\pi \mathrm{L}}\right) \times \left(\frac{(1-(\mathrm{v}_1)^2)}{\mathrm{E}_1} + \frac{(1-(\mathrm{v}_2)^2)}{\mathrm{E}_2}\right) / \left(\frac{1}{\mathrm{d}_1} + \frac{1}{\mathrm{d}_2}\right)} \quad \text{..........} 3.92$$

$$P_{max} = \left(\frac{2\mathrm{F}}{\pi \mathrm{bL}}\right) \quad \text{..........} 3.93$$

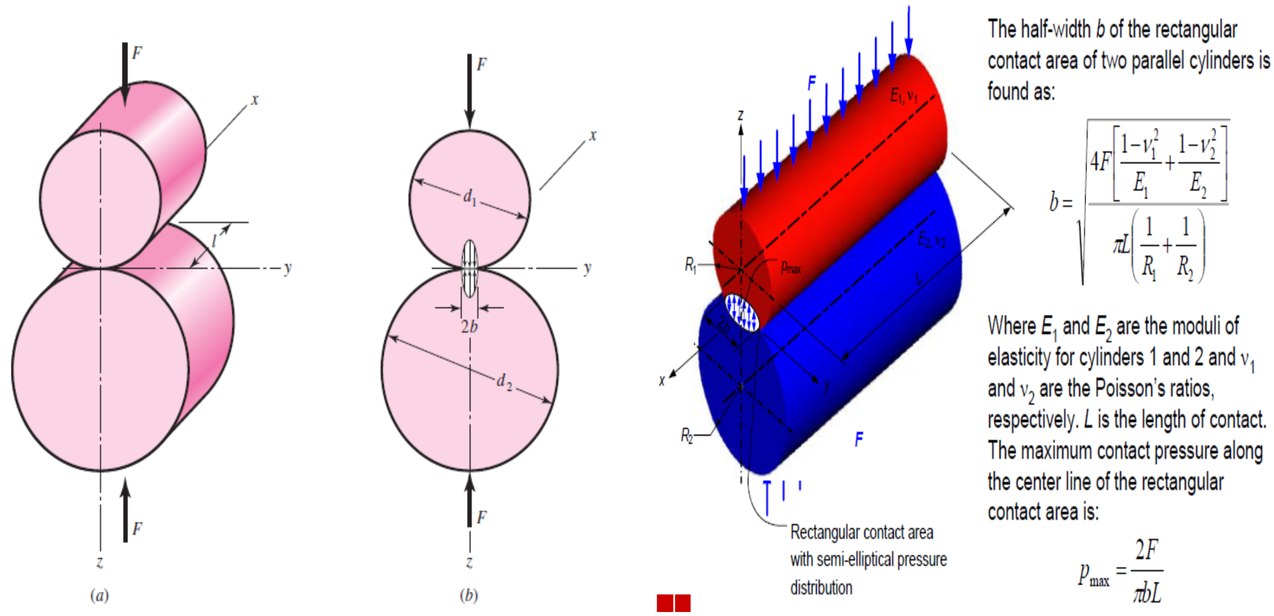


Fig. 13 The contact stress between two cylinders

According to (Richard et.al., 2011), the above equations apply to a cylinder and a plane surface (d= ∞) contact. When the equations are used to estimate the half width contact length and the pressure produced for cylindrical object and a plane surface contact, some of the parameters will have different values.

Where:- v_1 = Poisson ratio of steel, 0.3

v_2 = Poisson ratio of sandy soil, 0.25-0.4

E_1 = Young's modulus of elasticity of steel, 200GPa

E_2 = Young's modulus of elasticity of sandy soil, 10-50MPa (loose to compact)

d_1 = Diameter of the wheel, 0.57m

d_2 = Diameter of the contacting surface, ∞

F = The force exerted by the wheel, 295N

L = Contact length/width of the wheel with the ground, 0.1m

P_{min}= The minimum cone-index of the ground at 0-10 cm depth and 14.16% moisture content in wet basis, 550 KPa

The width of wheel specified in the design was 10cm and this had to be checked whether the width selected would allow the wheels to rotate on the surface of the ground without sinkage or not. The pressure (Pmax) developed on the contact patch (wheel and ground) was compared with the minimum con-index (Pmin) measured at 0-10cm depth using cone-penetrometer. If Pmax<Pmin, it is assumed that the width of the wheel is safe. However, if Pmax > Pmin, the width of the wheel has to be increased to some level to avoid wheel sinkage in operation.

- Solving for b,

$$b = \sqrt{\left(\frac{2\times 295\mathrm{N}}{\pi\times 0.1\mathrm{m}}\right) \times \left(\frac{(1-(0.3)^2)}{200\times 10^9 \mathrm{P_a}} + \frac{(1-(0.25)^2)}{50\times 10^6 \mathrm{P_a}}\right) / \left(\frac{1}{0.57\mathrm{m}} + \frac{1}{\infty \mathrm{m}}\right)}$$

b = 4.48 × 10-3 m

- Solving for $P_{max,}$

$$P_{max} = \left(\frac{2\times 295\mathrm{N}}{\pi\times 4.48 \times 10{-}3\mathrm{m}\times 0.1\mathrm{mL}}\right)$$

$P_{max} = 419.14 \times 10^3\ P_a$

Pmax = 419.14 KP_a

Since $P_{max} < P_{min}$, the selected size of the width of the wheels is safe and the wheel will rotate on the surface of the ground without parts of it sinking into the soil.

3.4.5. Chain design

Power transmission in the new planter from the wheel to the shaft on which the metering plates are placed was through chain and sprocket. Therefore, the velocity of the chain, its strength and length had to be determined.

3.4.5.1. Chain velocity

Average chain velocity (Kurtz *et al.* 1984)

$$V_{av} = \frac{N \times P \times RPM}{376} \qquad \text{..........} 3.94$$

$$V_{av} = \frac{30 \times 0.25\mathrm{in} \times 46.54\ \mathrm{rev/min}}{376} = 0.928\ \mathrm{m/sec}$$

Where:-

N = The driving sprocket no. of teeth, 30

RPM = Maximum revolution of the driving sprocket, 5Km/hr = 46.54 rev/min

P= Commercially available chain pitch, 6.35mm = 0.25in

V_{av} = Average chain velocity, m/sec

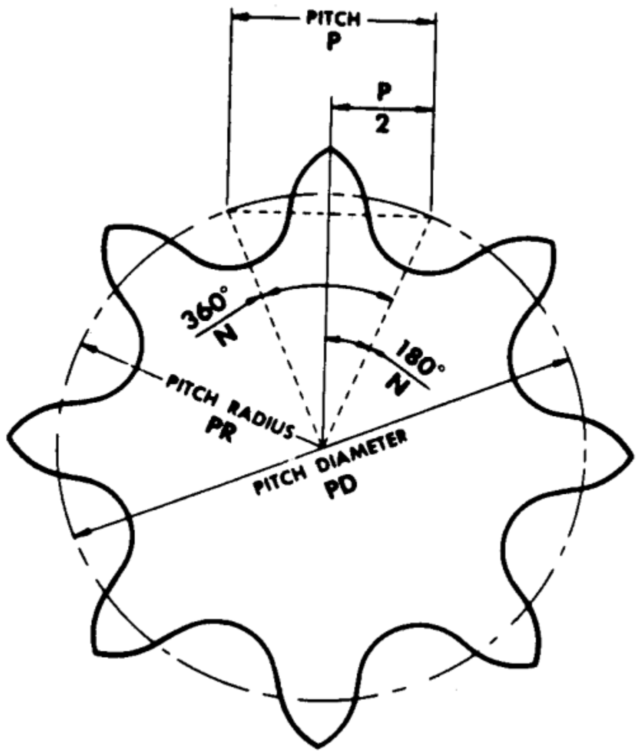


Fig.14 – Computation of sprocket pitch diameter

3.4.5.2. Chain force (Sharma and Mukesh, 2010)

The total load (force) on the driving side of the chain is given by

$F_T = F + F_c + F_f$ 3.95

where :-

F_T = The total force, N

F = The force due to power transmission, N

F_f = Frictional force, N

F_c = Centrifugal force on the chain, N

$F = \frac{P}{V_{av}}$……………………………………………………………………………...…….3.96

$F = \frac{114.48w}{0.928\ m/sec}$

F =123.36 N

Where:-

P = Power at the planter wheel/ power to be transmitted, 114.48w = 0.156Hp

$F_C = \frac{W \times (V_{av})^2}{g}$ ……………………………………..……………………..……………3.97

$F_C = \frac{6.60N/m \times (0.928\ m/sec)^2}{9.81m/s2}$

$F_C = 0.624$ N

Where:

W = Weight per meter of the chain, 6.60N/m

g = Gravitational attraction, 9.81m/s2

$F_f = W \times kf \times Cc$…………………………………………………..……………….……….3.98

$F_f = 6.60\ N/m \times 1 \times 0.19\ m$

$F_f = 1.254$ N

Where:-

k_f = Friction factor= 4 for horizontal drive, 2 for inclined drive and 1 for vertical drive since the sprockets are vertical aligned , $k_f = 1$

Cc = Nominal center to center distance between the sprockets, 0.19m

Thus,

F_T = 123.36N + 0.624N + 1.254N

F_T = 125.24N

American National Standard Institute (ANSI) test reveals that chain number 25 has minimum tensile strength (Tsm) of 3470N. So, the safety factor must be more than unity in order the chain to be safe from failure or breakage.

Checking for the safety factor, S_f (Sharma and Mukesh, 2010)

$$S_f = \frac{T_{sm}}{F_T} \quad \text{.........3.99}$$

$$S_f = \frac{3470N}{125.24N}$$

$$S_f = 27.71$$

Where:

T_{sm} = Tensile strength

S_f = Safety factor

Therefore, we can conclude that the chain is safe from breakage.

3.4.5.3. Chain length (Sharma and Mukesh, 2010) and (Ajit K. et.al. 2012)

The length of the chain is calculated based on the following formula.

$$L_c = P \times L_p \quad \text{.........3.100}$$

But, $$L_p = 2C_p + \frac{(N_1+N_2)}{2} + \left(\frac{(N_2-N_1)}{2\pi}\right)^2 / C_p \quad \text{.........3.101}$$

Where:

L_c = Chain length, m

L_p = Chain length, in pitches

C_p = Center to center distance between the sprockets, in pitches

N_1= Number of teeth of the driven sprocket, 15

N_2= Number of teeth of the driving sprocket, 30

But, $$C_p = \frac{C_c}{p} \quad \text{.........3.102}$$

Where:

C_c= Approximate center to center distance between the sprockets, 190 mm

P = Chain pitch, 6.35mm

$C_P = \frac{190 \text{ mm}}{6.35\text{mm}}$

C_P = 29.92

Thus, $L_p = 2 \times 29.92 + \frac{(15+30)}{2} + (\frac{(30-15)}{2\pi})^2 /29.92$

Lp = 82.42 pitches

We should take the pitches in whole number, 82 pitches

Hence, L_c= 6.35 mm × 82 pitches

L_c = 520.70 mm

L_c = 0.52 m

Now, since the chain length in pitches is changed from 82.42 to 82 pitches, the center to center distance of the sprockets has to be corrected using the following equations: (D.N. Sharma and S.Mukesh, 2010)

$C= (e + \sqrt{e2 - 8m}\ ) \times P/4$ ……………………………………………….........................3.103

But,

$e = L_p - \frac{(N_1+N_2)}{2}$…………………………………………………..…………3.104

$e = 82 - \frac{(15+30)}{2}$

e = 59.50

And, $m = (\frac{(N_2-N_1)}{2\pi})^2$ ……………………………………………………..………3.105

$m = (\frac{(30-15)}{2\pi})^2$

m = 5.70

Therefore, the corrected center to center distance between the sprockets is

$C= (59.50 +\sqrt{(59.50\ )^2 - 8(5.70)}\ ) \times \frac{6.35}{4}$

C = 188.3

C ≈ 189 mm

3.4.6. Shaft design

The shafts are often subjected to torsion, axial tension, bending and compression or to a combination of any or all of these actions of failure loads shocks and stress concentration. Consequently, the design of the shaft most involve the determination of the minimum diameter of the shaft material to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading conditions..

3.4.6.1. Determination of the Drive Shaft Diameter

The shaft was initially decided to be fabricated from ductile material (mild steel rod). Hence, the design was based on ductile material whose strength is controlled by maximum shear stress. For a shaft having little or no axial loading, the diameter of the shaft was obtained using the following equation, (ASME, 1995) given as:

$$d^3 = \frac{16}{\pi Ss} \times [(K_bM_b)^2 + (K_tM_t)^2]^{1/2} \quad \ldots\ldots 3.106$$

Where:-

d = Diameter of the shaft; mm

M_b = Bending moment; Nm

M_t = Torsional moment; Nm

Ss = Allowable stress; MN/m

K_b = Combined shock and fatigue factor applied to bending moment;

K_t = Combined shock and fatigue factor applied to torsional moment;

For rotating shafts, when load is suddenly applied with minor shock, Khurmi and Gupta (2005) recommended that values of K_b = 1.2 to 2.0 and K_t = 1.0 to 1.50 to be used. Furthermore, it was noted that for shaft without key way, the allowable stress (Ss) must be 55 MN/m2, and for the shaft with key way the allowable stress (Ss) should not exceed 40 MN/m2.

Torsional moment (Mt) on the shaft was calculated using formula: (Ryder, 1989).

$$M_t = \frac{P \times 60}{2\pi \times N} \quad \ldots\ldots 3.107$$

But, $P = V \times F$

$P = 1.39 m/s \times 82.43 N$ ….see page 14 and 52

$P = 114.49$ W

Therefore,

$$M_t = \frac{114.49 \text{ W x } 60}{2\pi \ x \ 46.54\text{rpm}}$$

$$M_t = 23.49\text{Nm}$$

Where:-

P = Power required to drive the machine; w

N = Speed of the shaft, 46.54RPM

V = Forward speed, 5Km/hr = 1.39m/s

F = Force required to drive the machine, 82.43N

Fig.15 shows the load distribution on the shaft. The maximum bending moment on the shaft was determined from the following expressions (Richard et.al, 2011)

$$M_b = \sqrt{(M_V)^2 + (M_h)^2} \quad \ldots 3.108$$

Where:-

M_b = Maximum bending moment, Nm

M_v = Vertical bending momentum, Nm

M_h = Horizontal bending momentum, Nm

The load diagram on the driven wheel shaft is as shown below

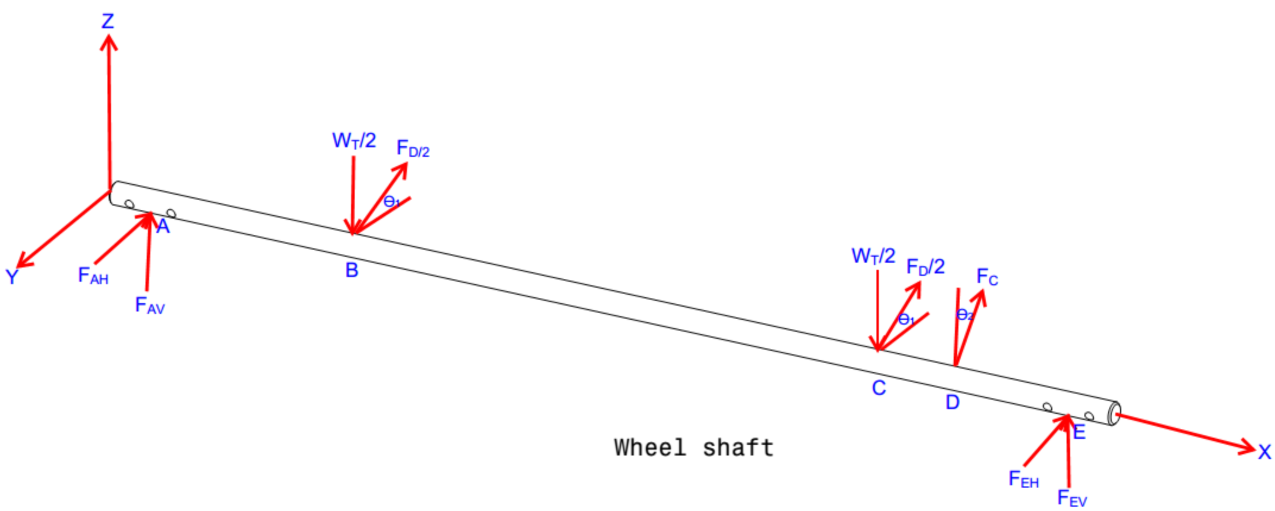


Fig.15 3D free body diagram of the wheel shaft

Where:-

F_{AH} = Wheel reaction in horizontal direction at point A, N

F_{AV} = Wheel reaction in vertical direction at point A, N

W_T = Total weight of the prototype, 590N

F_D = Draft force, 107.91N (11Kgf) from dynamometer reading

F_C = Force due to chain pull, 125.24N

F_{EH} = Wheel reaction in horizontal direction at point E, N

F_{EH} = Wheel reaction in vertical direction at point E, N

According to the study conducted by Kefyalew the maximum mean draft force of 778.28N was noted with a pair of oxen and followed by camel 563.30 N and donkey 475.58N (Kefyalew,2014, unpublished). So, the planter can be pulled easily because the draft force required to pull the prototype, reading from dynamometer, was 107.91N (11kgf) which is very much less than the pull performance of Ethiopian draft animals.

Step1 determining the angle the chain force acting on the shaft (see figure. 16)

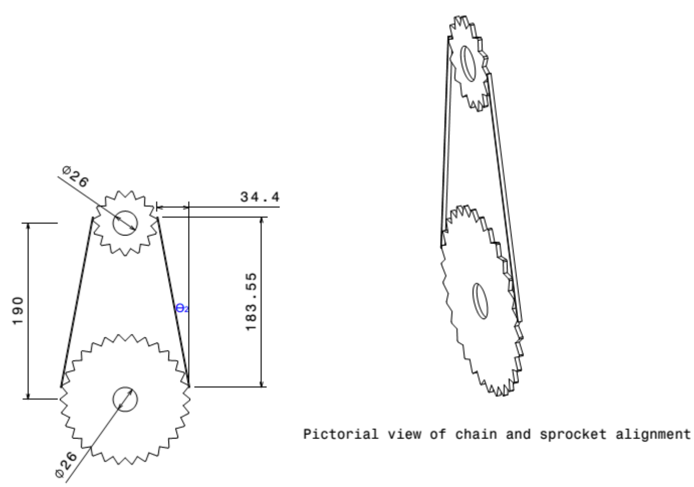


Fig. 16 Chain force application angle (dimensions are in mm)

Therefore, the angle through which the chain force acts from the vertical

$$\tan \Theta_2 = \frac{34.4}{183.55} = 0.187$$

$$\Theta_2 = \tan^{-1} 0.187$$

$$\Theta_2 = 10.62^0$$

Step2 determining the angle the draft force acting on the bearings (see fig. 17)

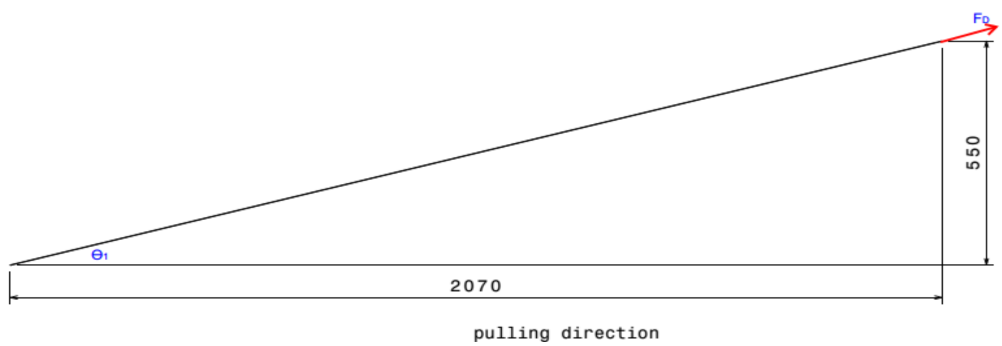


Fig. 17. Draft force application angle (dimensions are in mm)

$$\tan \theta_1 = \frac{550\text{mm}}{2070\text{mm}} = 0.266$$

$$\theta_1 = \tan^{-1} 0.266$$

$$\theta_1 = 14.88^0$$

Step3 loads on the shaft (fig. 18) in the vertical plane **(ZY)**

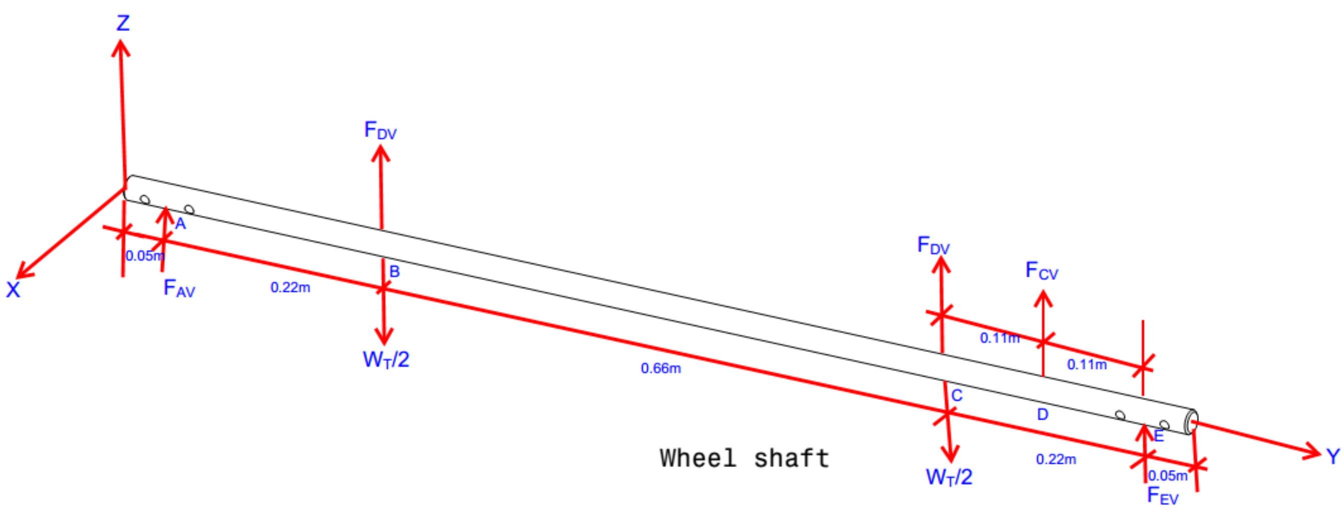


Fig. 18. Load diagram of the wheel shaft in ZY plane

But, $F_{DV} = 1/2F_D \sin \theta_1$

$F_{DV} = ½ \times 107.91\text{ N} \times \sin 14.88^0$

$F_{DV} = 13.86\text{ N}$

And, $F_{CV} = F_C \cos \theta_2$

$F_{CV} = 125.24\text{ N} \times \cos 10.62^0$

$F_{CV} = 123.10\text{ N}$

Substitute the above values and the forces acting on the wheel shaft could be:

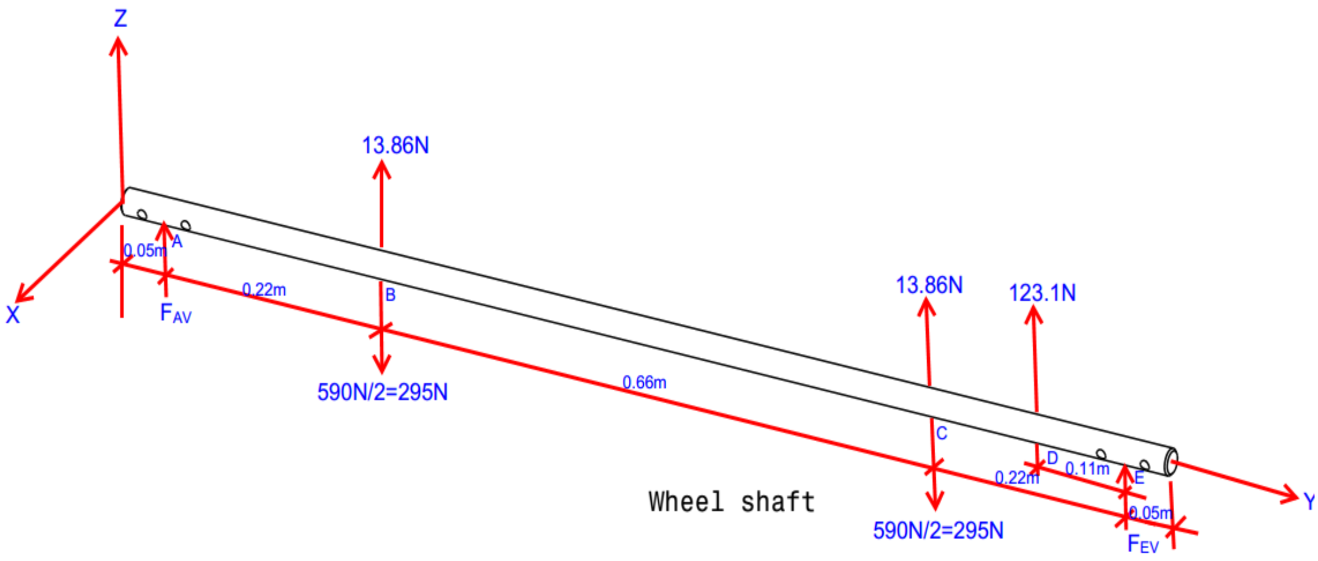


Fig. 19 Loads on wheel shaft in ZY plane

To find the unknown forces which were F_{AV} and F_{EV} equilibrium equations were used

$\sum M_E = 0$, (CCW is postive)

295N×0.88N + 295×0.22 - 13.86N×0.88m - 13.86N×0.22m – 123.10N×0.11m - F_{AV}×1.1m =0

F_{AV} = 268.83 N

$\sum F_E = 0$, (upward is postive)

F_{AV} +F_{EV}+13.86 N + 13.86 N +123.10 N -295 N – 295 N = 0

But,

F_{AV} = 268.83 N

Thus,

F_{EV} = 170.35 N

Step 4. Shear and bending moment diagrams of the loads on the shaft in ZY plane (Fig. 20)

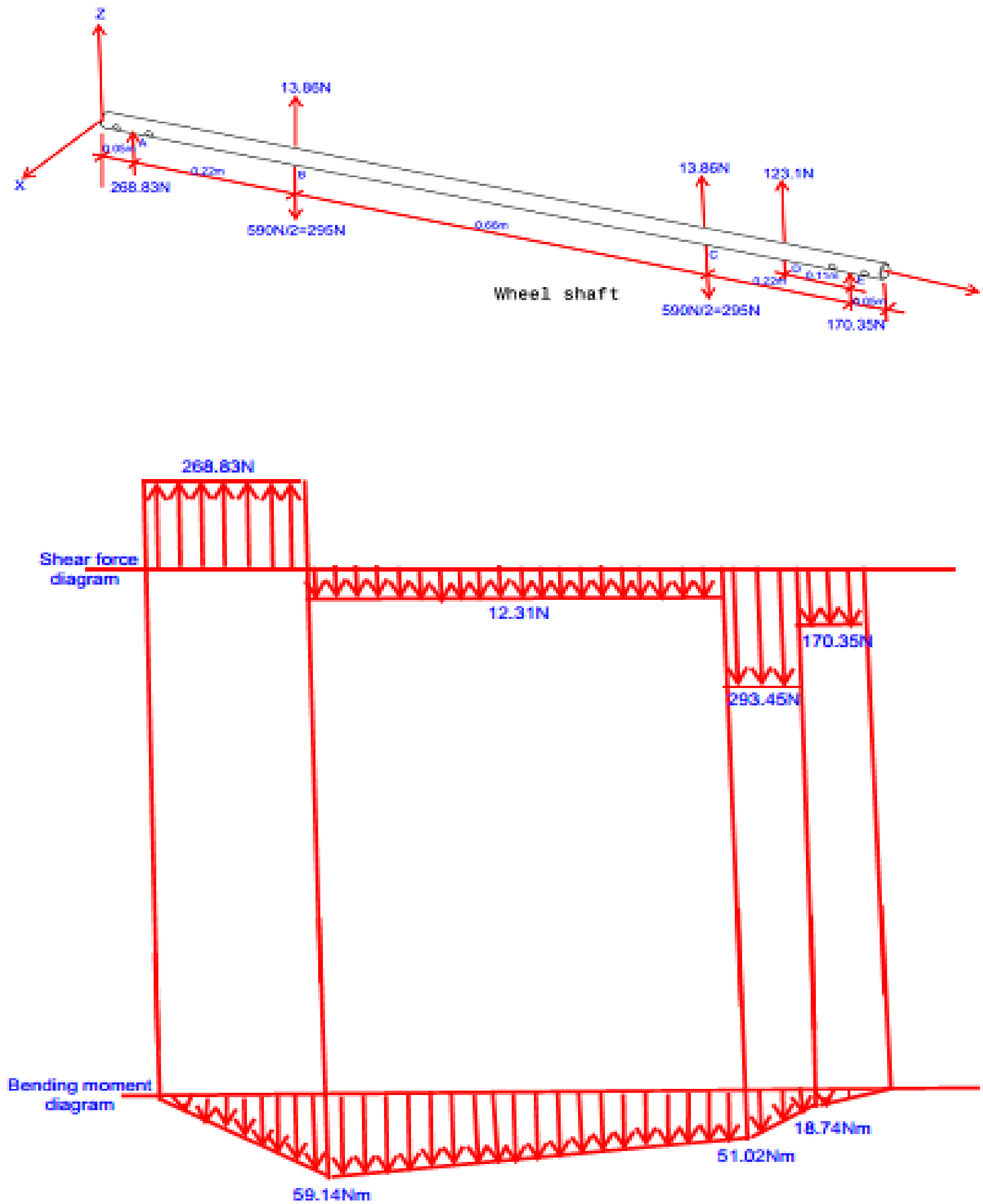


Fig. 20 Shear and bending moment diagrams of the main shaft in ZY plane

Therefore, the maximum vertical bending moment, $\mathbf{M_V = 59.14\ Nm}$

Step 5. Loads on the shaft (fig. 21) in the horizontal plane (ZX)

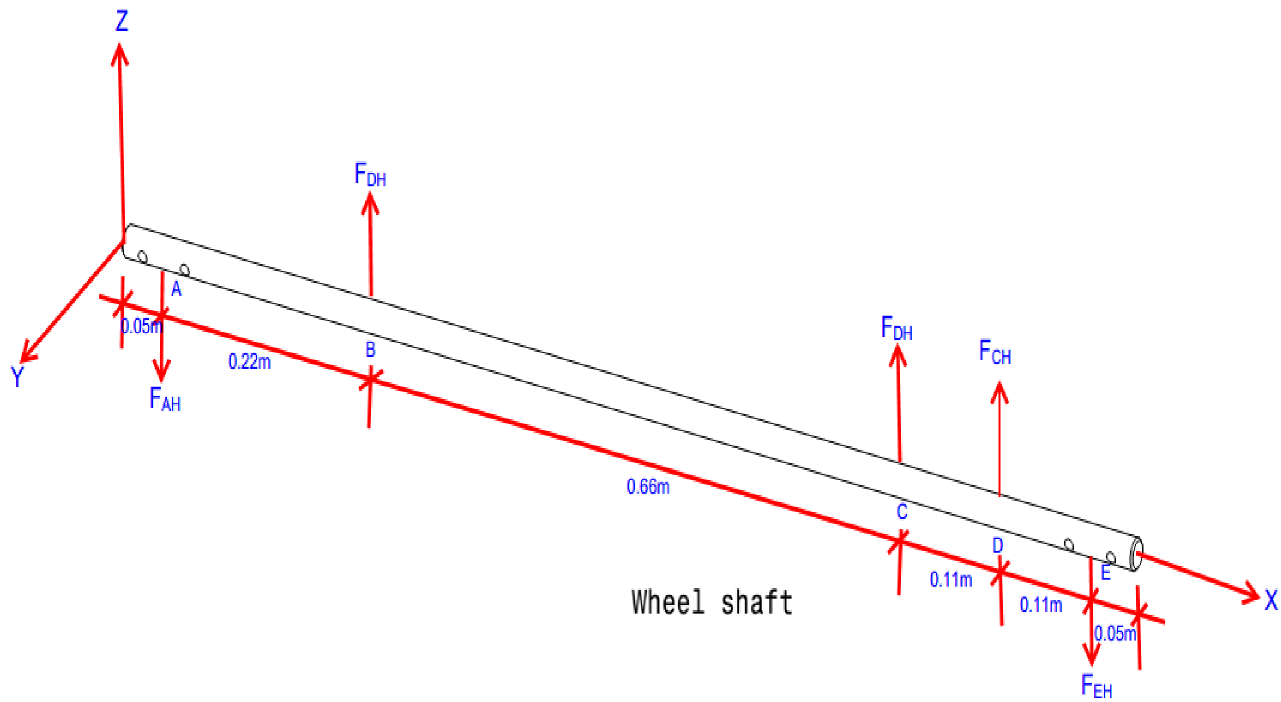


Fig. 21. Load diagram of the wheel shaft in ZX plane

But, $F_{DH} = 1/2 \times F_D \times \cos \Theta_1$

$F_{DH} = ½ \times 107.91N \times \cos 14.88^0$

$F_{DH} = 52.15$ N

And, $F_{CH} = F_C \sin \Theta_2$

$F_{CH} = 125.24 \text{ N} \times \sin 10.62^0$

$F_{CH} = 23.08$ N

Substitute the above values and the forces acting on the wheel shaft could be:

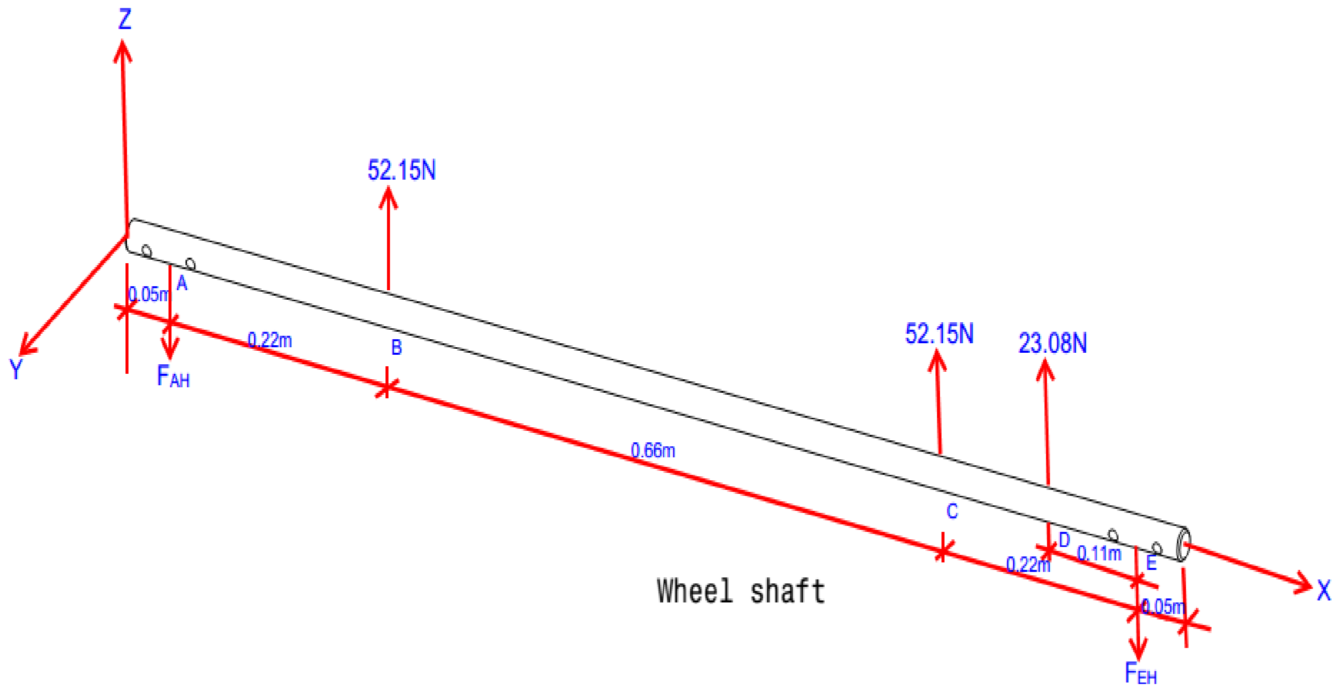


Fig. 22. Load on wheel shaft in ZX plane

To find the unknown forces which were F_{AH} and F_{EH}, equilibrium equations were used

$\sum M_E = 0$, (CCW is postive)

$F_{AH} \times 1.1m – 52.15N \times 0.88m – 52.15N \times 0.22m – 23.08N \times 0.11m = 0$

$F_{AH} = 54.46$ N

$\sum F_E = 0$, (upward is postive)

$F_{AH} + F_{EH} – 142.55$ N - 52.15 N – 52.15 N = 0

But,

$F_{AH} = 54.46$ N

Thus,

$F_{EH} = 72.92$ N

Step 6. Shear and bending moment diagrams of the loads on the shaft in ZX plane (fig. 23)

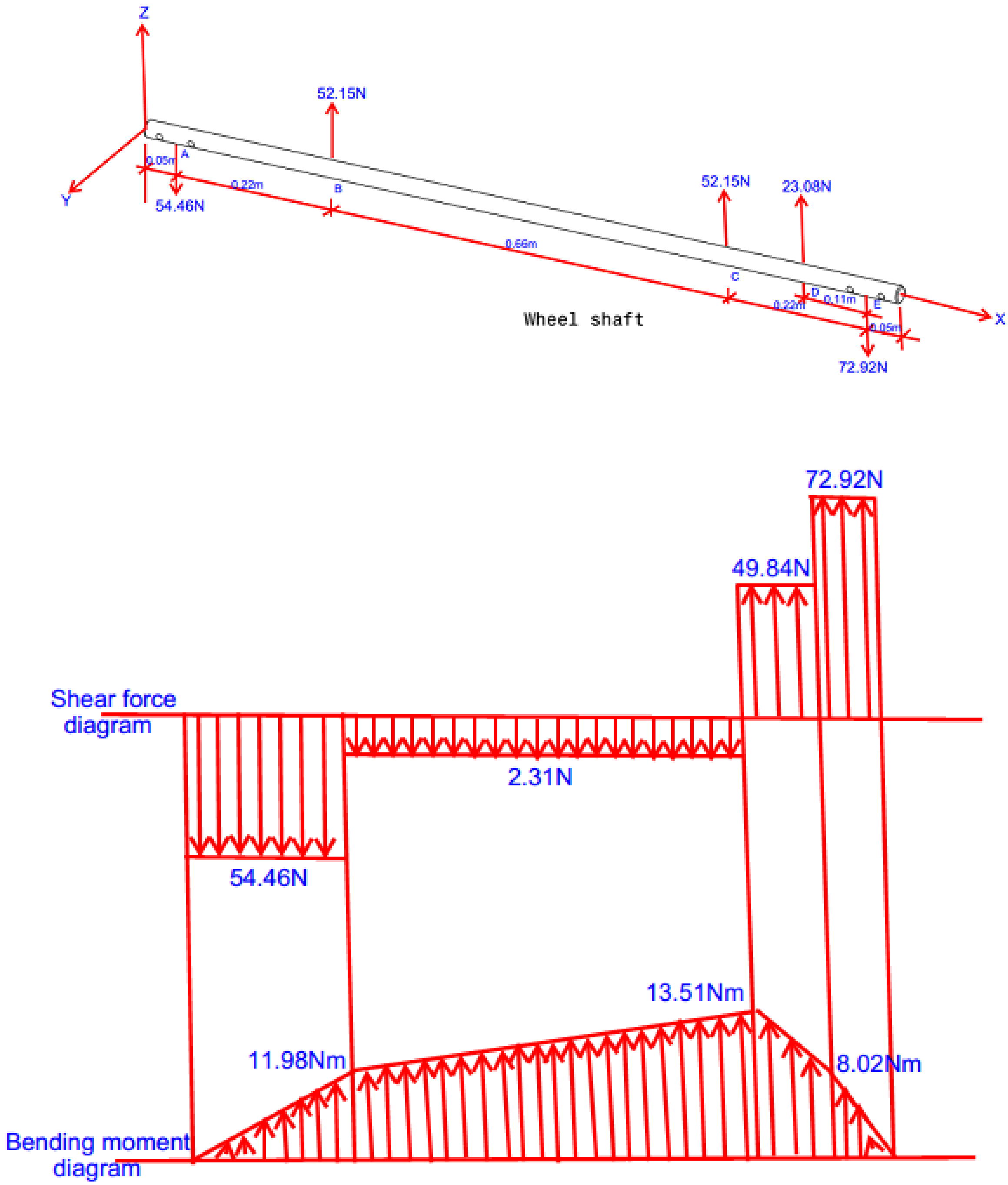


Fig. 23 Shear and bending moment diagrams of the main shaft in ZX plane

Therefore, the maximum horizontal bending moment,$\mathbf{M_h}$ **= 13.51 Nm**

Hence,

$$M_b = \sqrt{(59.14\ \text{Nm})^2 + (13.51\text{Nm})^2}$$

$$M_b = 60.66\ \text{Nm}$$

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

$$d^3 = \frac{16}{\pi \times 55 \times 10^6 \frac{N}{m^2}}\sqrt{(2 \times 60.66\ \text{Nm})^2 + (1.5 \times 23.49\ \text{Nm})^2}$$

$$d^3 = 11.7 \times 10^{-6}\ m^3$$

$$d = 0.02270\ m$$

$$d = 22.70mm$$

Therefore, the standard size of **25 mm** shaft diameter has been used.

3.4.7. Design of Shank for Shoe type furrow Opener

The furrow-opening tool is attached at one extreme end of the shank and other end of the shank is fixed to the frame by nuts and bolts as shown in Fig. 1. Considering lower push/pull available and easy operation of planter, a Shoe type furrow Opener, which places the fertilizer 2.5cm to the side of the seed. The draft force exerted to the opener was determined using the following equation: (Kurtz et al. 1984)

$$D = k_o \times w \times d \quad \text{……} \quad 3.109$$

Where:-

D = Draft force, kgf.

k_0 = Specific soil resistance, kg / cm2.

= 0.25 kg / cm^2 is selected (Table 3.1) for heavy soils (considering the worst case)

w = Width of furrow, cm.

d = Depth of furrow, cm.

Table 3.1. Specific soil resistances at a depth of 15 cm

S.No.	Soil type	Specific resistance, kg/cm^2.
1.	Light	0.12
2.	Medium	0.15
3.	Heavy	0.20
4.	Very heavy	0.25

(Source: Dubey 2003.)

Assuming, w = 12 cm, d = 10 cm and k_o= 0.75 kg/cm2 substituting the values in the above equation the draft force could be:

D = 0.25 × 12 × 10 = 30 kgf.

Now taking factor of safety as 1.5; therefore, total draft exerted on the opener would be,

D= 30 × 1.5 = 45 kgf.

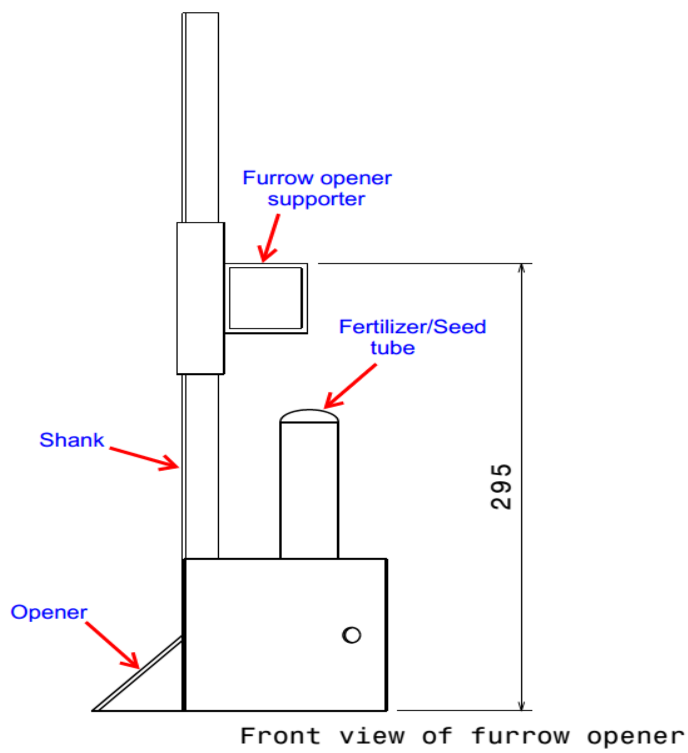


Fig.24. Shoe type furrow Opener (dimensions are in mm)

The shank can be taken as a cantilever, so the maximum bending moment for a cantilever length of 29.5cm and draft 45 kgf could be (Kurtz et al. 1984) using the following equation

Bending moment (M) = Draft (kgf) × Length of shank (cm)…………………...………. 3.110

Bending moment (M) = 45kgf x 29.5cm = 1327.50 kgf- cm.

Therefore, Section modulus of the furrow opener, was calculated by using the formula 3.4 (Seely et al. 1995 and Timoshenko et al. 1964)

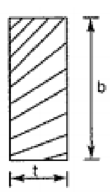
$Z = \frac{M}{\delta}$..3.111

Substituting the value of bending moment (M) = 1327.50kgf- cm, and assume Bending stress (δ) = 1000 kgf/ cm^2 (Sengar, 2002). The section modulus could be:

$Z = \frac{1327.50\ \mathrm{kgf-cm}}{1000\mathrm{kgf}/_{\mathrm{cm}^2}}$

$Z = 1.33\ cm^3$

Z = 1.33 cm3



$Z = \frac{t \times b^2}{6}$…………………………………………………………………….....3.112

Assume b=20mm = 2cm

$1.33\ cm^3 = \frac{t \times (2cm)^2}{6}$

t= 1.99cm ≈ 2cm

Therefore the cross-section of the shank will be,

b × t = 20×20 mm2.

This section would a maximum deflection, and that deflection can be

determined by using the eq. 3.114, (Seely et al. 1995 and Timoshenko et al. 1964)

$$y_{max} = \frac{D \times l^3}{3EI} \quad \text{..........} 3.114$$

Where:-

y_{max} = Deflection produced due to loading, mm

D = Draft force, 45kgf

l = Length of the shank up to frame, 29.5cm = 295mm

E = Modulus of elasticity, $2x10^4 kgf/mm^2$(for mild steel)

I = Moment of inertia, mm^4

$$\text{But, } I = \frac{t \times x\, b^3}{12} \quad \text{..........} 3.115$$

Where:-

t = width of shank, 20mm

b = length of shank, 20mm

Hence,

$$I = \frac{20mm \times 20mm^3}{12}$$

$I = 13,333.33mm^4$

Therefore,

$$y_{max} = \frac{45kgf \times (295mm)^3}{3 \times 2\, x10^4 kg/mm^2 \times 13,333.33mm^4}$$

$y_{max} = 1.44mm$

3.5. Performance Test and Evaluation

A new animal drawn sorghum row planter developed at AIRIC, MARC, was evaluated for its performance by conducting laboratory and field test. Before directly conducted the performance test, the machine was subjected to a preliminary test run was undertaken mainly to ascertain that the main functional parts of the machine was functionally acceptable or not and to check the existence of any malfunctioning parts and defects. Fortunately, the prototype planter had good stability in terms of operation and performed the intended job acceptably. After this, two sets of tests were performed; laboratory investigation to calibrate the machine in terms of seed rate, seed damage, and seed spacing, and field tests carried out to obtain actual overall performance of the machine.

3.5.1. Laboratory evaluation

The planter prototype parts after fabrication were coupled and taken to the laboratory. The laboratory tests was carried out at Melkassa Agricultural Research Center (MARC) and the machine was calibrated in the laboratory to determine the seed and fertilizer application rate, uniformity of seed spacing, seed damage during operation and physical properties of the seed.

3.5.1.1. Seeding and fertilizer application rate of the planter

The seeding and fertilizer application rates of the planter were measured at four levels of the hoppers loads; quarter, half, three-fourth and full loads and the prototype planter was pulled manually with average speed of 1Km/hr, 3Km/hr, and 5Km/hr, so as to know if there were significant variations on rating and seed damage /external/. Polythene bag was placed on each of the discharge tubes or sprouts to collect the seeds or fertilizers discharged. The seeds or fertilizers collected on each bag were weighed for the determination of the seeding and fertilizer application rates of the planter and the test was replicated three times on 30m length ground (with negligible gradient and moderate moisture content). Weight balance (0.1gm accuracy) and stop-watch were the instruments used for measurement.

3.5.1.2. Evaluation of percent seed damage

The test for percentage seed damaged was done on the discharged seeds from each sprout or tubes during the above test for any external damage. The dropped seed was sorted out for healthy seed and damaged seed then the sorted seed was counted. Total three readings were taken for each setting. The average value of these readings showed the percentage damage of seed due to metering mechanism. Percentage external seed damage was determined by equation given below (Ashebir, 2015)

$$\mathrm{Md} = \frac{\mathrm{Stds}}{\mathrm{Sns}} \times 100 \quad \ldots 3.116$$

Where:-

Md = Percentage damaged seed

Stds = Total number of damaged seeds (external)

Sns = Total number of seeds

The seeds which had passed through the seed metering mechanism were also subjected for germination tests so as to know if there were internal damage which may be caused by the metering plate /change in its velocity/and the weights of the seeds in the hopper. The germination rate of the seeds was tested from 50 randomly selected seeds discharged from the tubes using Petri-dish. Ten seeds were placed in each Petri-dish and awaited for a week until most of the seeds start germinating.

3.5.1.3. Uniformity of seed spacing

The prototype planter was evaluated both at laboratory and field using predetermined hopper loads and working speeds. The planter was designed to drop two to three seeds per spot keeping the recommended 15cm spacing between two consecutive hills. The seed spacings were measured on ground with negligible gradient covered with a thin layer of saw dust and hay /having 10m length and 100 cm widths/ in order to avoid seed bounce during seed dropping. The number of seeds dropped on each hill were also counted and analyzed. The test was replicated three times on each cases and human power was used to pull the planter at desired speeds.

Seed spacing uniformity was evaluated in terms of the mean seed spacing, seed multiple index (MULTI), seed miss index (MISI), quality of feed index (QFI) and precision index (PREC). Mean values and standard deviation of seed spacing were determined to pattern and uniformity of seed distribution in the rows (Kachman and Smith, 1995).

Theoretical spacing, xref, in the design of wheels and metering devices was used as actual seed spacing and the measured and its mean values of spacing were compared against the theoretical values. Accordingly, the observed spacings were classified into five divisions:-

Division I = 0 to 0.5 of xref, this indicated multiple seeds dropped at the same spot or seed spacings less than or equal to half of the desired spacing.

Division II = 0.5 to 1.5 of xref, this indicate single seed spacings close to the theoretical seed spacings.

Division III =1.5 to 2.5 xref, these are single skips.

Division IV = 2.5 to 3.5 xref, these are double skips.

Division V = over 3.5 xref, these are triple skips etc.

Seed spacing accuracy estimation was based on the following parameters and equations (Kachman and Smith, 1995):-

Multiples index (MULTI)

It is the percentage of spacing that are less than or equal to half of the theoretical (nominal) spacing. The MULTI was calculated as follows (Kachman and Smith, 1995)

$$\text{MULTI } (\%) = \frac{n_I}{N} \times 100 \qquad \ldots 3.117$$

Where:-

MULTI = Multiple index, (%)

n_I = The number of spacings in region I

N = Total number of spacings.

Miss index (MISI)

It is the percentage of spacing greater than 1.5 times the theoretical (nominal) spacing. The MISI was calculated as follows (Kachman and Smith, 1995)

$$\text{MISI (\%)} = \frac{n_{III} + n_{IV} + n_{V}}{N} \times 100 \quad \ldots\ldots 3.118$$

Where:-

MISI = Miss index, (%)

n_{III}, n_{IV}, n_{V} = The number of spacing in division III, IV, and V

N = Total number of spacing.

Quality of feed index (QFI)

It is the percentage of spacing values that are more than half but not more than 1.5 times the theoretical (nominal) spacing. This is the measure of how close the actual spacing value is the theoretical (nominal) spacing value. The QFI was calculated as follows (Kachman and Smith, 1995)

$$\text{QFI (\%)} = \frac{n_{II}}{N} \times 100 \quad \ldots\ldots 3.119$$

Where:-

QFI = Quality of feed index , (%)

n_{II} = The number of spacing in division II

N = Total number of spacings.

Precision index (PREC)

It is the coefficient of variation of the spacing between the nearest seeds in a row that were classified as singles after omitting the outliers consisting of misses and multiples (Singh etal., 2005). Precision is similar to a coefficient of variation for the spacings that are classified as singles (i.e. seeds in division II). The percentage precision in spacing was calculated as follows (Kachman and Smith, 1995)

$$\text{PREC (\%)} = \frac{S_{II}}{X_{ref}} \times 100 \quad \ldots\ldots 3.120$$

Where:-

PREC = Precision. (%)

S_{II} = The standard deviation of the N observations in zone II

X_{ref} = The theoretical spacing.

The standard deviation was calculated according to the following equation (Kachman and Smith, 1995)

$$S_{II} = \sqrt{\frac{\sum_{i=1}^{N}(X_i - X_{ref})^2}{N-1}} \quad \text{.....................3.121}$$

Where:-

X_i = Specified seed spacing, mm.

N = Total number of tuber spacings.

3.5.2. Field evaluation

The field tests were also carried out at Melkassa Agricultural Research Center (MARC) for the determination of effective field capacity, field efficiency and average depth of placement of seeds, evenness of seed spacing in the field and ease of setting, operation and adjustments on $10x40m^2$ rectangular ground having a sandy-loam soil texture. The field was properly ploughed and harrowed to have a good soil condition for the crop and a workable environment for the planter. Investigation on field capacity and field efficiency of the planter involved continuous observation and timing of each activity and time losses for turning at head lands, removal of clogs and adjustment.

Investigation into the working speed, field efficiency and effective field capacity of the planter involved continuous observation and timing of each activity involved in the planting operation. Two stop clocks were used to time the activities, while three people were involved in the determination of field efficiency. One person operated the planter on the prepared field, while others observed, took and recorded the time for the activities. One stop clock was used to record the time losses such as those for turning at field ends, removal of clogs and adjustment. The other stop clock was used to continuously measure the time during which the planter actually performed the intended operation.

3.5.2.1. Working speed

The working speed was estimated using the expressions below (Kepner et al 1978)

$$V = \frac{\mathrm{D}}{t_a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.122$$

Where:-

V = Working speed,(m/s)

D = Distance of run (m)

t_a = Average time of each pass (second)

3.5.2.2. Field efficiency

To determine the field efficiency of the planter, the planting operation was performed longitudinally with a constant forward speed as determined by noting the distance of travel using measuring tape and the corresponding time to complete the distance with the aid of a stop watch while planting the area of the prepared field. The effective operating time and the time spent to fill the hopper, remove stumps and other obstructions (Afzalinia et al, 2006). The field efficiency was evaluated from equation (120) suggested by (Kepner et al 1978).

$$\mathcal{E} = \frac{\mathrm{Te}}{\mathrm{Tt}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.123$$

Where:-

Ɛ = Field efficiency (%)

Te = Effective operating time (min)

Tt = Total time (min) (effective operating time + time lost for turning)

3.5.2.3. Effective field capacity

The effective field capacity was determined by measuring the effective width of the planter using a measuring tape and the forward constant speed of the planting operation. The effective field capacity was suggested by (Kepner et al, 1978).

$$E_C = \frac{\mathrm{WS}}{10} \times \mathcal{E} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.124$$

Where:-

E_C = Effective field capacity,(ha/hr)

W = Implement effective width, (m)

S = Forward speed, (km/hr)

Ɛ = Field efficiency, % (decimal)

3.5.2.4. Planting depth and furrow width

The average planting depth and furrow width of the seeds were determined by running the planter to and fro over a length of 40 meters. Along each furrow, ten randomly selected locations/points for depth and width of furrow were investigated. The Planter was operated without covering mechanism (furrow covering device). A measuring tape was used to measure the required depth.

3.5.2.5. Plant population density

Plant population, or rather seed emergence, count was the other parameter that was measured. Six rows on $400m^2$(10m* 40m) were selected at the twenty one date of planting and the plant-populations data were measured. When count plants, three samples were taken within a row on three meter intervals along the length field and this measurement replicated for six rows on the field area

3.5.2.6. Draft requirement test

The draft requirement for sowing sorghum was measured with the help of spring dynamometer. The dynamometer was tied between harness of donkey and frame of the planter. The deflection of dial was recorded during operation of the planter. During the test the planter was operated with furrow opener. The measurement was conducted on actual field (avg. 12.55% moisture content) using a portable dynamometer. The angle of pull was 14.88^0 from the horizontal.

3.6. Economic evaluation

The cost of operation for the machine was worked out by calculating the fabrication, fixed and variable costs as presented in Appendix G. Estimation of annual and hourly operational costs of the planter were based on capital cost of the planter, interest on capital, cost of repairs and spare parts, labor cost, and depreciation. The operational cost components of the prototype planter were estimated in Birr (EB) as follows: (Ashebir T, 2015)

Depreciation(D_P), was calculated as follows:

$$D_P = \frac{CC-SVC}{EL}, \text{ (EB/h)} \quad \text{3.125}$$

Interest on capital (IC), was calculated as follows:

$$IC = \left(\frac{CC+SVC}{2}\right) \times \left(\frac{I\%}{NAOHP}\right), \text{ (EB/h)} \quad \text{3.126}$$

Labor wages (LW), was calculated as follows:

$$LW = \frac{DLW}{DWH}, \text{ (EB/h)} \quad \text{3.127}$$

Cost of repairs and spares (CRS) was calculated as follows:

$$CRS = \frac{CC \times 6\%}{AWHP}, \text{ (EB/h)} \quad \text{3.128}$$

Wage of oxen (WO), was calculated as follows:

$$WO = \frac{DOW}{DWH}, \text{ (EB/h)} \quad \text{3.129}$$

Hourly operational costs = (D_P + IC + LW + CRS + WO)…………………………..…………3.130

Where:-

Dp = Depreciation

CC = Capital cost

SVC = Selvage Cost

CRS = Cost of repairs and spares

EL= Estimate life (h)

I = Interest %

DLW = Daily labor wage

DWH = Daily working hours (EB/h)

IC = Interest on capital (EB/h)

WO = Wage of oxen

DOW = Daily oxen wage (EB/h)

LW = Labor wages

NAOHP = Number of the annual operational hours of the planter (EB/h)

AWHP = Annual working hours of the planter

3.7. Data analysis

All the data collected during the laboratory and field performance evaluations were analyzed using Statistix 8 software. Statistix 8 is a commercial software package developed by the United States Department of Agriculture (USDA). It was chosen by a team of Plant Materials scientists based upon a number of factors. Ease of use and ability to import data from spreadsheets are two of the factors that weighed in heavily during the selection process. It provides almost all of the statistical analysis techniques that the Plant Materials Program will ever use.

4. RESULTS AND DISCUSSIONS

The planter prototype parts after fabrication were coupled and taken to the laboratory and field for testing in order to compromise the effect of forward speed and hopper loading on the recommended seed space, seed rate and seed damage. Physical properties of seeds also involved in the study were investigated to optimize the design of the planter's component parts because the range of shapes and sizes of agricultural grain crops and their physical properties like grain length, width and thickness are used in designing of scoop size on the seed and fertilizer metering unit. Performance indicators such as seed damage, seed germination, seed rate, spacing indices that include seed multiple index (MULTI), seed miss index (MISI), quality of feed index (QFI) and precision (PREC) in seed spacing, planting depth, field efficiency and field capacity were used to assesses functional fulfillment of the prototype planter. The following are details of the physical properties of the seeds used and performance evaluation of the machine.

4.1. Laboratory Test Results

4.1.1. Physical Properties of the Seeds

In order to get some of the physical properties of the seed, 50 sample seeds were randomly taken and their length, width and thickness were measured. So, table 4.1 contains the arithmetic mean, geometric mean, volume, and sphericity of the sorghum grain. The average values obtained for arithmetic mean, volume, geometric diameter and sphericity of the selected sorghum seed became 20.31mm^3, 3.38mm and 84.34% respectively, and its 1000 seed weight found to be 27.04gm.

The arithmetic mean and geometric mean can therefore be used to determine the average diameter of sorghum grain. This is useful in determining the diameter and depth of metering scoops; in addition to this, sphericity of sorghum seed also indicates that the shape of metering scoops. Since the mean sphericity of sorghum was 84.34%, the seeds had more or less spherical shape. Hence, it was decided to have metering devices with circular shape where the depths were equal to the length or major diameters of the seeds of the crops. .

Table 4.1 shows the results obtained from the measuring the sorghum seed and it gives the mean values and the standard deviations of length, width, thickness, Volume, geometric diameter, and sphericity

Description	Seed Dimension (mm)					
	Length (mm)	Width (mm)	Thickness (mm)	Volume (mm^3)	Geometric diameter(mm)	Sphericity (%)
Samples size	50	50	50	-	-	-
Mean	4.01	3.91	2.47	20.31	3.38	84.34
Mode	4.10	3.80	2.50	-	-	-
SD	0.14	0.16	0.18	2.11	0.12	2.84
C.V.	3.55	3.99	7.22	10.38	3.51	3.37
Minimum	3.70	3.5	2.10	15.45	3.09	77.09
Maximum	4.3	4.2	3.00	25.1	3.63	90.01
Volume(mm^3)	20.31					
Geometric diameter(mm)	3.38					
Sphericity (%)	84.34					

4.1.2. Seed Damage Test

The numbers of mechanically damaged, i.e. bruised, skin removed or crushed seeds were counted and their percentage was computed out of 50 randomly selected seeds of discharged from each sprout or tubes during the test. Table 4.2 shows the effect of working speed and hopper loading on mechanical damage of the seed during operation out of 50 randomly selected seeds of discharged from each sprout or tubes during the test. The maximum percentage of seed damaged sorghum seeds were 0.67% and ANOVA (analysis of variance) test showed that no significant variations among the means of the treatments. The above result found when the forward speed and hopper loading were 5Km/hr and one-fourth of full load respectively. Which shows that planter could effectively perform the sowing operation with minimum seed damage.

Table 4.2 shows the effect of working speed and hopper loading on mechanical damage of the seed during operation out of 50 randomly selected seeds of discharged from each sprout or tubes during the test.

Source of variation (speed * hopper loading)							
parameter	Working speed(Km/hr)	Hopper loading (Kg)				P (5%)	CV
		Full	¾ of full	½ of full	¼ of full		
No of mechanical mean Seed damage out of 50 seeds	1	0.00	0.00	0.00	0.00	0.012	300.00
	3	0.00	0.00	0.00	0.00		
	5	0.00	0.00	0.00	0.33		

4.1.3. Seed Germination Test

Germination test was also conducted on the seeds that had passed through the metering system of the designed planter in order to know if there was any unnoticeable (internal) damage due to the meeting system using Petri-dish and awaited for a week until most of the seeds start germinating. Germination tests, on randomly picked 50 seed samples, which were free from any mechanical damage, were conducted before testing the performance of the prototype. The result showed that the seeds had 79.33% seedling. After this germination test also conducted the seeds which had passed through the seed metering mechanism that were free from mechanical damage and the result showed that the seeds had 78.67% seedling. From the above two results, the seed percentage of germination which had passed through the seed metering mechanism was 99.16%. Based on the above two test result percent of seed damage (include both internal and external seed damage) was 1.5%.

4.1.4. Seed Rate Test

Table 4.3 shows the effect of working speed and hopper loading on the application seeding rate.

Source of variation(speed * hopper loading)							
parameter	Working speed(Km/hr)	Hopper loading (Kg)				P (5%)	CV
		Full	¾ of full	½ of full	¼ of full		
Mean Seed rate(Kg/ha)	1	15.47	15.34	15.31	15.27	0.91	0.94
	3	15.21	15.11	15.03	15.02		
	5	15.02	14.97	14.85	14.72		

The seeding rate application of the machine were tested at four levels of hopper loading and at three working speed which ware determined above and the grand mean of seed rate was 15.08Kg/hr. Since $P < 0.05$ ANOVA (analysis of variance) test showed that no significant variations among the means of the treatments.

4.2. Field Test Results

4.2.1 Evaluation of Seed Spacing/Distribution

4.2.1.1. The Seed Multiple Index (MULTI)

The statistical analysis ANOVA revealed that the interaction of planter working speed and hoper loading level had not significant effect ($p > 0.05$) on seed multiple indexes. The highest MULTI (21.67%) was obtained at forward speed of 1km/hr and full hopper loading, while the lowest MULTI (13.34%) resulted from working speed of 5Km/hr and one-quarter of full hopper loading. The average multiple index for the data taken along the planted rows was 16.71%. This means that only 16.71% the seed spacing's were less than or equal to 7.5cm. Since, with a theoretical spacing of 15 cm in this study. Table 4.4 summarizes the analysis of variance (p values) of the effects of the forward speed and hopper loading on seed spacing uniformity. Due the fact that, at low forward speed, the scoops may have the chance to carry more than the recommended amount of seeds so, the table showed that at low forward speed the MULTI value was high

Table 4,4. Seed multiple index

Source of variation (speed * hopper loading)							
parameter	Working speed(Km/hr)	Hopper loading (Kg)				P (5%)	CV
		Full	¾ of full	½ of full	¼ of full		
MULTI (%)	1	21.67	21.11	20.56	19.45	0.77	10.96
	3	15.55	14.44	15.55	15.56		
	5	13.89	14.44	15.00	13.34		

4.2.1.2. The Seed Miss Index (MISI)

The seed miss index for all the levels of hopper loading and forward speed of operation was found zero. This means that none of the sorghum was dropped at spacing greater than 1.5 times the theoretical (nominal) spacing or greater than 22.5cm. Since, with a theoretical spacing of 15 cm in this study.

4.2.1.3. Quality of Feed Index (QFI)

The statistical analysis ANOVA revealed that the interaction of planter working speed and hoper loading level had not significant effect ($p > 0.05$) on quality of feed index. The highest QFI (86.66%) was obtained at forward speed of 5Km/hr and one-quarter of full hopper loading, while the lowest QFI (78.343%) resulted from working speed of 1km/hr and full hopper loading. The average quality of feed index for the data taken along the planted rows was 83.29%. This means that only 83.29% the seed spacing's were on the distance interval between 7.5cm to 22.5cm. Since, with a theoretical spacing of 15 cm in this study. Table 4.5 summarizes the analysis of variance (p values) of the effects of the forward speed and hopper loading on seed spacing uniformity.

Table 4.5. Summarizes quality of feed index

Source of variation(speed * hopper loading)							
parameter	Working speed(Km/hr)	Hopper loading (Kg)				P (5%)	CV
		Full	¾ of full	½ of full	¼ of full		
QFI (%)	1	78.33	78.89	79.44	80.55	0.77	2.20
	3	84.45	85.56	84.45	84.44		
	5	86.11	85.00	85.56	86.66		

4.2.1.4. The Seed Precision Index (PREC)

The statistical analysis ANOVA revealed that the interaction of planter working speed and hoper loading level had not significant effect ($p > 0.05$) on the seed precision index. The highest PREC (29.13%) was obtained at forward speed of 1km/hr and full hopper loading, while the lowest PREC (11.20%) resulted from working speed of 5Km/hr and one-quarter of full hopper loading. The average multiple index for the data taken along the planted rows was 16.81%. This indicates that tinning work should be performed eventually in order to avoid competitions among the germinated seeds.

Table 4.6. Shows the effects of working speed and level of hopper loading on the seed precision index

Source of variation(speed * hopper loading)							
parameter	Working speed(Km/hr)	Hopper loading (Kg)				P (5%)	CV
		Full	¾ of full	½ of full	¼ of full		
PREC (%)	1	29.13	22.41	17.93	13.45	0.27	24.94
	3	15.69	20.17	13.45	11.21		
	5	15.96	17.93	13.45	11.20		

4.2.2. Field efficiency and field capacity of the planter

As shown in Table 4.7 the average value of the mean field capacity and field efficiency of the prototype planter obtained from the trials were 0.39 ha/hr (2.56 hr/ha) and 80.03 %, respectively. This satisfactory result is due to its maneuverability which saves time in moving and turning the planter from one point to another

Table 4.7 shows mean field efficiency and field capacity

Determination of Field efficiency and field capacity of the planter				
Time spent for	Average time to cover 168m^2, sec	Average time to cover hectare,hr	Field efficiency, Ɛ Ɛ=Te/Tt X100, %	Field capacity, E_C E_C = WS/1000* Ɛ%
Turning at field end	30.90	0.51	80.38%	Since W = 1.4m S = 3.42Km/hr E_C = 0.39ha/hr
Removal of clogs	-	-		
Adjustment	-	-		
Actual planting, T_e	126.45	2.09		
Total time, T_t	157.35	2.60		

4.2.3. Planting depth and furrow width

Table 4.8 show the depth and width measurements observed. In the determination of the depth of furrow opener and furrow width were 5.22 ± 0.56 cm with coefficient of variation of 0.11 (10.79%) and 14.75 ± 0.85 cm with coefficient of variation of 0.06 (5.74%) respectively. These planting depth values were slightly more than the desired depth of planting of 4-5 cm as recommended for sorghum by agronomists (Akinsanmi, 1975). Nonetheless, the deviation and the variability being too small and with acceptable range, also, it can be adjusted to the desired depth of planting. Large coefficient of variation was recorded due to land preparation because if the farm land is undulated, the depth of furrow would be varying from place to place.

Table 4.8 Shows mean planting depth and furrow width

Average furrow depth and width of cut along 40 m row			
Trials	Row	Average width of cut, (cm)	Average depth of cut, (cm)
Trip 1	1	9.5	4.88
	2	11.5	6.08
Trip2	3	10.5	5.42
	4	9	4.45
Trip3	5	11	5.46
	6	10	5.02
Average furrow depth (cm)		10.25	5.22
C.V		9.13	10.79
SD		0.94	0.56

The assumption of width and depth of the furrow which were taken to design the shank of furrow opener was higher than the actual width and depth of furrow (see page 69). So, the designed shank could resist the coming loads because the load acting on the shank is lower than the assumed loads.

4.2.4. Plant Population

Table 4.8 show the seed emerge count which was done after 21 days from the planting date. The numbers of emerged seeds were counted with in 3m along each row in the area of 400m^2 (10m × 40m). The optimum average plant population per three meter length was 25.22 against theoretical plant population of 20 plants. This was calculated with assumptions of more than one seed with in 5cm radius considered as single plant. Hence the planter reasonably satisfied the requirement for the establishment of optimum plant population for all seed types.

Table 4.8 Shows mean plant population count

Average plant population count		
Trials	Row	Average plant population over 3m
Trip 1	1	25.67
	2	24.33
Trip2	3	24.00
	4	26.00
Trip3	5	24.67
	6	26.67
Average plant population		25.22
C.V		4.15
SD		1.05

4.2.5. Draft requirement test

Draft requirement of the new planter was the other parameter which was measured on actual field condition using a dynamometer. The angle of pull during measurement was 14.88^0 (see fig. 17) and the average draft force required by the planter was 9.6 Kgf with coefficient of variation of 0.16 (16.16%). Table 4.9 show descriptive statistics of the draft force and the values are not large enough to induce stress on the pulling animals. This was the result of the presence of wheels and their designed width which helped the planter to rotate over the surface of a ground without significant sinkage.

Table 4.9 shows descriptive statistics of the draft force on field

Description	On field
Number of observation	15
Mean, Kgf	9.33
SD	1.59
C.V.	17.02
Minimum, Kgf	5.00
Maximum, Kgf	11.00

4.3. Economical evaluation

Manual placement of seeds and fertilizer required three persons; one to do the ploughing and the other two to plant and apply fertilizer. But, the prototype row planter required only one person to effect planting and fertilizing. The time required to plant and fertilizes a hectare of land using manual method, with three persons, was 26 hours (Melesse, 2007), while a single person, using the prototype planter, required only 2.56 hours*ha-1 to do the same work as indicated in the section above. Hence, one can note that the time requirement per hectare is reduced by ten times and labour requirement reduced by the one-third when the prototype planter was used. Nonetheless, the cost of the planter which is estimated to be 7,071.55Birr appears to be high for a single farmer to purchase and own the machine. However, joint ownership or custom use, owning, using and renting out will definitely off-set the initial price of purchasing the planting machine.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

Ethiopia is the largest sorghum producing country in Eastern and Southern Africa next to Sudan. The grain is a highly versatile crop with many uses including human food, animal feed, for brewing and bio-fuels beside, which is widely grown in the country in 13 of the 18 major agro-ecological zones. The crop is a staple food for many of the Ethiopian's most food insecure people who live in marginal areas with poor and erratic rains so, millions of poor Ethiopians depend on the crop. As a result, Agricultural sector requires modern techniques and suitable agricultural mechanization which will increase the production and productivity of sorghum, and reduce the level of manual labor, by introducing sorghum row planter to the target area. So, this study was undertaken to design, fabricate and evaluate the performance of a prototype animal drawn planter capable of planting sorghum seed at predetermined spacing and depths.

Physical properties of seeds also involved in the study were investigated to optimize the design of the planter's component parts because the range of shapes and sizes of agricultural grain crops and their physical properties like grain length, width and thickness are used in designing of scoop size on the seed and fertilizer metering unit. Performance indicators such as seed damage, seed germination, seed rate, spacing indices that include seed multiple index, seed miss index, quality of feed index and precision in seed spacing, planting depth, field efficiency and field capacity were used to assesses functional fulfillment of the prototype planter. The sphericity of sorghum was 84.34%, Hence, scoops with circular shape were used in the design. Evaluation made to assess level of mechanically seed damaged, i.e. bruised, skin removed or crushed seeds, indicated that mean percent seed damage was 0.67%. Germination tests conducted to assess the effect of metering devices on the magnitude and extent of seed damage using metered seeds, revealed mean percentage germination of 99.16%. The seeding rate application of the machine were tested at four levels of hopper loading and at three working speed and the grand mean of seed rate was 15.08Kg/hr.

The combined effect of speed and level of hopper had no significant effect ($P > 0.05$) on mean percent of multiple indexes, miss index, feed index , precision index and their mean value were 16.71%, 0%, 83.29% and 16.81% respectively.

The mean field capacity and efficiency of the prototype planter were 0.39 ha/hr (2.56 hr/ha) and 80.03 % respectively. According to (Kepner et al,1978) the field efficiency of the prototype planter, is within the acceptable level. of the depth of furrow opener and furrow width were 5.22 ± 0.56 cm with coefficient of variation of 0.11 (10.79%) and 14.75 ± 0.85 cm with coefficient of variation of 0.06 (5.74%) respectively. These planting depth values were slightly more than the desired depth of planting of 4-5 cm as recommended for sorghum by agronomists (Akinsanmi, 1975).

The seed emerge count which was done after 21 days from the planting date. The numbers of emerged seeds were counted with in 3m along each row in the area of 400m2 (10m* 40m). The optimum average plant population per three meter length was 25.22 against theoretical plant population of 20 plants. This was calculated with assumptions of more than one seed with in 5cm radius considered as single plant. Hence the planter reasonably satisfied the requirement for the establishment of optimum plant population for all seed types

Draft requirement of the new planter was the other parameter which was measured on actual field condition using a dynamometer. The angle of pull during measurement was 14.880 (see figure 17) and the average draft force required by the planter was 9.6 Kgf with coefficient of variation of 0.16 (16.16%). This showed that the draft force produced by the planter is not large enough to induce stress on the pulling animals

Manual placement of seeds and fertilizer required three persons; one to do the ploughing and the other two to plant and apply fertilizer. But, the prototype row planter required only one person to effect planting and fertilizing. The time required to plant and fertilizes a hectare of land using manual method, with three persons, was 26 hours (Melesse, 2007), while a single person, using the prototype planter, required only 2.56 hours-ha-1 to do the same work as indicated in the section above. Hence, one can note that the time requirement per hectare is reduced by ten times and labour requirement reduced by the one-third when the prototype planter was used. Nonetheless, the cost of the planter which is estimated to be 7,071.55Birr appears to be high for a single farmer to purchase and own the machine. However, joint ownership or custom use, owning, using and renting out will definitely off-set the initial price of purchasing the planting machine

Table 5.1 summarized details of the physical properties of the seeds used and performance evaluation of the machine.

Over all summary of animal drawn sorghum row planter		
Over all dimension of the planter		
Length		1210mm
Width		605mm
Height		648mm
Component of the planter	Frame, Hopper, Hopper lid, Funnel, Metering device, Furrow opener, Furrow closer, Wheel, Chain and Sprocket	
Seeds were used during the test		Sorghum (variety, Awash 2)
Laboratory test results		
Physical properties of seeds	Average length of the seed	4.01mm
	Average width of the seed	3.91mm
	Average thickness of the seed	2.47mm
	Average volume of the seed	20.31mm^3
	Average geometric diameter of the seed	3.38mm
	Average sphericity of the seed	84.34%
Average seed rate		15.08Kg/hr
Average seed damage		0.67%
Average germination rate		99.16%
Field test results		
Seed spacing indexes	Seed multiple index (MULTI)	16.71%
	Seed miss index (MISI)	0%
	Quality of feed index (QFI)	83.29%
	Seed precision index (PREC)	16.81%
Average planting depth		5.22cm
Average field efficiency		80.03 %
Average field capacity		2.56 hr/ha

5.2. Conclusion

The two-row animal drawn sorghum planter was fabricated to match the need and alleviated the difficulties of rural, small and medium scale farmers. It can be adjusted to meter more seeds per discharge, according to the recommendation seed rate and did not require any special skill to operate. Based on the experimental results, the performance of the prototype planter in terms of seed rate, seed damage, germination rate, percent of average spacing indexs like, quality of feed index, multiple index, miss index and precision, depth of planting, field capacity, field efficiency are observed within the recommended levels, and also labour cost and economics of owning and operating the machine is acceptable. Hence, it can be concluded that the prototype planter can be efficiently, effectively and economically used by the majority of Ethiopian farmers. However, this doesn't mean that it shouldn't be improved.

5.3. Recommendations

The performance evaluations made indicated that the prototype planter can be used successfully on farms at home. Nonetheless, the following improvement and issue must be addressed to make the planter popular, adaptable and usable among the farmers.

- Slight modification is required to minimize tinning work
- It also recommended that this machine has to be multiplied and disseminated, so that the sorghum farmers have to get it and use it in order to increase their productivity with a minimum cost.
- Promote joint ownership or owning, operating and renting (lease) to minimize the annual fixed and ease the initial cost by distributing among the potential users; and
- Finally, I recommend that there is a possibility to convert it in to a multi crop seeder by adjusting the depth of scoops found on the circumferences of the plate.

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7. APPENDICES

Appendix A: physical property of the sorghum seed

A.1. Average length of the seed

	LENGTH
N	50
Mean	4.0120
SD	0.1423
C.V.	3.5479
Minimum	3.7000
Maximum	4.3000

A.2. Average width of the seed

	WIDTH
N	50
Mean	3.9080
SD	0.1563
C.V.	3.9991
Minimum	3.5000
Maximum	4.2000

A.3. Average thickness of the seed

	THICKNESS
N	50
Mean	2.4720
SD	0.1785
C.V.	7.2198
Minimum	2.1000
Maximum	3.0000

A.4. Average volume of the seed

	VOLUME
N	50
Mean	20.313
SD	2.1091
C.V.	10.383
Minimum	15.450
Maximum	25.100

A.5. Average geometry mean of the seed

	GEOMEAN
N	50
Mean	3.3822
SD	0.1189
C.V.	3.5143
Minimum	3.0900
Maximum	3.6300

A.6. Average sphericity of the seed

	SPHERICIT
N	50
Mean	84.340
SD	2.8431
C.V.	3.3710
Minimum	77.090
Maximum	90.010

Appendix B: Analysis of variance of seed rate

Analysis of Variance Table for RATE

Source	DF	SS	MS	F	P
REP	2	0.04965	0.02483		
LOADING	3	0.32665	0.10888	7.48	0.0189
Error REP*LOADING	6	0.08737	0.01456		
SPEED	2	1.64347	0.82173	41.18	0.0000
LOADING*SPEED	6	0.04089	0.00681	0.34	0.9046
Error REP*LOADING*SPEED	16	0.31924	0.01995		
Total	35	2.46728			

Grand Mean 15.086
  CV(REP*LOADING) 0.80
  CV(REP*LOADING*SPEED) 0.94

LSD All-Pairwise Comparisons Test of RATE for LOADING*SPEED

LOADING	SPEED	Mean	Homogeneous Groups
100	1	15.473	A
50	1	15.343	AB
75	1	15.310	AB
25	1	15.270	AB
100	3	15.217	BC
75	3	15.113	BCD
50	3	15.027	CDE
100	5	15.023	CDE
25	3	14.973	DE
75	5	14.853	EF
25	5	14.723	F
50	5	14.703	F

Comparisons of means for the same level of LOADING
  Alpha 0.05 Standard Error for Comparison 0.1153
  Critical T Value 2.120 Critical Value for Comparison 0.2445
  Error term used: REP*LOADING*SPEED, 16 DF
Comparisons of means for different levels of LOADING
  Alpha 0.05 Standard Error for Comparison 0.1100
  Critical T Value 2.207 Critical Value for Comparison 0.2428
  Error terms used: REP*LOADING and REP*LOADING*SPEED
There are 6 groups (A, B, etc.) in which the means
are not significantly different from one another.

Appendix C: Analysis of variance of seed breakage

Analysis of Variance Table for BREAKAGE

Source	DF	SS	MS	F	P
REP	2	0.05556	0.02778		
LOADING	3	0.33333	0.11111	4.00	0.0701
Error REP*LOADING	6	0.16667	0.02778		
SPEED	2	0.22222	0.11111	4.00	0.0390
LOADING*SPEED	6	0.66667	0.11111	4.00	0.0123
Error REP*LOADING*SPEED	16	0.44444	0.02778		
Total	35	1.88889			

Grand Mean 0.0556
CV(REP*LOADING) 300.00
CV(REP*LOADING*SPEED) 300.00

LSD All-Pairwise Comparisons Test of BREAKAGE for LOADING*SPEED

LOADING	SPEED	Mean	Homogeneous Groups
25	5	0.6667	A
25	1	0.0000	B
25	3	0.0000	B
50	1	0.0000	B
50	3	0.0000	B
50	5	0.0000	B
75	1	0.0000	B
75	3	0.0000	B
75	5	0.0000	B
100	1	0.0000	B
100	3	0.0000	B
100	5	0.0000	B

```
Comparisons of means for the same level of LOADING
  Alpha              0.05     Standard Error for Comparison  0.1361
  Critical T Value  2.120     Critical Value for Comparison  0.2885
  Error term used: REP*LOADING*SPEED, 16 DF
Comparisons of means for different levels of LOADING
  Alpha              0.05     Standard Error for Comparison  0.1361
  Critical T Value  2.229     Critical Value for Comparison  0.3033
  Error terms used: REP*LOADING and REP*LOADING*SPEED
There are 2 groups (A and B) in which the means
are not significantly different from one another.
```

Appendix D: Analysis of variance of seed spacing

D.1. Analysis of variance of the seed multiple index (MULTI)

Analysis of Variance Table for MULTI

Source	DF	SS	MS	F	P
REP	2	30.739	15.370		
LOADING	3	4.516	1.505	0.28	0.8382
Error REP*LOADING	6	32.242	5.374		
SPEED	2	292.838	146.419	43.62	0.0000
LOADING*SPEED	6	10.958	1.826	0.54	0.7674
Error REP*LOADING*SPEED	16	53.708	3.357		
Total	35	425.002			

```
Grand Mean 16.713
  CV(REP*LOADING) 13.87
  CV(REP*LOADING*SPEED) 10.96
```

LSD All-Pairwise Comparisons Test of MULTI for LOADING*SPEED

LOADING	SPEED	Mean	Homogeneous Groups
100	1	21.667	A
75	1	21.110	A
50	1	20.557	A
25	1	19.447	A
25	3	15.557	B
50	3	15.553	B
100	3	15.553	B
75	5	15.000	B
50	5	14.443	B
75	3	14.443	B
100	5	13.887	B
25	5	13.337	B

```
Comparisons of means for the same level of LOADING
  Alpha              0.05     Standard Error for Comparison  1.4959
  Critical T Value  2.120     Critical Value for Comparison  3.1712
  Error term used: REP*LOADING*SPEED, 16 DF
Comparisons of means for different levels of LOADING
  Alpha              0.05     Standard Error for Comparison  1.6389
  Critical T Value  2.265     Critical Value for Comparison  3.7126
  Error terms used: REP*LOADING and REP*LOADING*SPEED
There are 2 groups (A and B) in which the means
are not significantly different from one another.
```

D.2. Analysis of variance of the quality of feed index (QFI)

Analysis of Variance Table for QFI

Source	DF	SS	MS	F	P
REP	2	30.739	15.370		
LOADING	3	4.516	1.505	0.28	0.8382
Error REP*LOADING	6	32.242	5.374		
SPEED	2	292.838	146.419	43.62	0.0000
LOADING*SPEED	6	10.958	1.826	0.54	0.7674
Error REP*LOADING*SPEED	16	53.708	3.357		
Total	35	425.002			

Grand Mean 83.287
CV(REP*LOADING) 2.78
CV(REP*LOADING*SPEED) 2.20

LSD All-Pairwise Comparisons Test of QFI for LOADING*SPEED

LOADING	SPEED	Mean	Homogeneous Groups
25	5	86.663	A
100	5	86.113	A
50	5	85.557	A
75	3	85.557	A
75	5	85.000	A
50	3	84.447	A
100	3	84.447	A
25	3	84.443	A
25	1	80.553	B
50	1	79.443	B
75	1	78.890	B
100	1	78.333	B

```
Comparisons of means for the same level of LOADING
  Alpha              0.05     Standard Error for Comparison  1.4959
  Critical T Value  2.120     Critical Value for Comparison  3.1712
  Error term used: REP*LOADING*SPEED, 16 DF
Comparisons of means for different levels of LOADING
  Alpha              0.05     Standard Error for Comparison  1.6389
  Critical T Value  2.265     Critical Value for Comparison  3.7126
  Error terms used: REP*LOADING and REP*LOADING*SPEED
There are 2 groups (A and B) in which the means
are not significantly different from one another.
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AM
```

D.3. Analysis of variance of the seed precision index (PREC)

Analysis of Variance Table for PREC

Source	DF	SS	MS	F	P
REP	2	30.15	15.075		
LOADING	3	446.89	148.965	8.09	0.0157
Error REP*LOADING	6	110.51	18.418		
SPEED	2	278.63	139.317	7.93	0.0041
LOADING*SPEED	6	162.99	27.165	1.55	0.2266
Error REP*LOADING*SPEED	16	281.22	17.577		
Total	35	1310.40			

Grand Mean 16.809
CV(REP*LOADING) 25.53
CV(REP*LOADING*SPEED) 24.94

LSD All-Pairwise Comparisons Test of PREC for LOADING*SPEED

LOADING	SPEED	Mean	Homogeneous Groups
100	1	29.130	A
75	1	22.410	AB
75	3	20.170	BC
75	5	17.930	BCD
50	1	17.930	BCD
100	3	15.690	BCD
100	5	15.690	BCD
25	1	13.450	CD
50	5	13.450	CD
50	3	13.447	CD
25	3	11.207	D
25	5	11.203	D

```
Comparisons of means for the same level of LOADING
  Alpha              0.05     Standard Error for Comparison  3.4231
  Critical T Value  2.120     Critical Value for Comparison  7.2567
  Error term used: REP*LOADING*SPEED, 16 DF
Comparisons of means for different levels of LOADING
  Alpha              0.05     Standard Error for Comparison  3.4503
  Critical T Value  2.232     Critical Value for Comparison  7.7022
  Error terms used: REP*LOADING and REP*LOADING*SPEED
There are 4 groups (A, B, etc.) in which the means
are not significantly different from one another.
```

Appendix E: Descriptive statistics of furrow depth, furrow width and plant population

E.1. Descriptive statistics of furrow depth

Descriptive Statistics

Variable	**Mean**	**SD**	**C.V.**	**Minimum**	**Maximum**
DEPTH	5.2183	0.5631	10.792	4.4500	6.0800

E.2. Descriptive statistics of furrow width

Descriptive Statistics

Variable	Mean	SD	C.V.	Minimum	Maximum
WIDTH	10.250	0.9354	9.1260	9.0000	11.500

E.3. Descriptive statistics of plant population

Descriptive Statistics

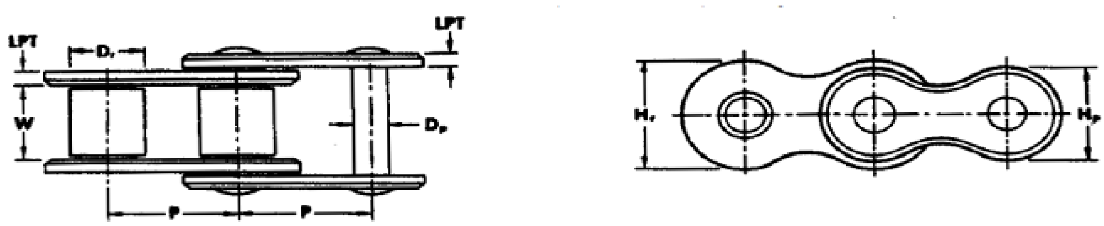
Variable	Mean	SD	C.V.	Minimum	Maximum
PLANTPOPN	25.223	1.0476	4.1535	24.000	26.667

Appendix F: Descriptive statistics of draft force

Descriptive Statistics

	DRAFT
N	15
Mean	9.3333
SD	1.5887
C.V.	17.021
Minimum	5.0000
Maximum	11.000

Appendix F. Chain standard (ANSI)



Standard Chain No.	Pitch P	Max. Roller Diam. D_r	Nominal Width W	Nominal Pin Diam. D_p	Link Plate Thickness LPT: Standard Series	Link Plate Thickness LPT: Heavy Series
25	6.35 (0.250)	3.30 (0.130)*	3.18 (0.125)	2.30 (0.090)	0.76 (0.030)	– –
35	9.52 (0.375)	5.08 (0.200)*	4.78 (0.188)	3.58 (0.141)	1.27 (0.050)	– –
41	12.70 (0.500)	7.77 (0.306)	6.35 (0.250)	3.58 (0.141)	1.27 (0.050)	– –
40	12.70 (0.500)	7.92 (0.312)	7.92 (0.312)	3.96 (0.156)	1.52 (0.060)	– –
50	15.88 (0.625)	10.16 (0.400)	9.52 (0.375)	5.08 (0.200)	2.03 (0.080)	– –
60	19.05 (0.750)	11.91 (0.469)	12.70 (0.500)	5.94 (0.234)	2.39 (0.094)	3.18 (0.125)
80	25.40 (1.000)	15.87 (0.625)	15.87 (0.625)	7.92 (0.312)	3.18 (0.125)	3.96 (0.156)
100	31.75 (1.250)	19.05 (0.750)	19.05 (0.750)	9.52 (0.375)	3.96 (0.156)	4.75 (0.187)
120	38.10 (1.500)	22.22 (0.875)	25.40 (1.000)	11.10 (0.437	4.75 (0.187)	5.56 (0.219)
140	44.45 (1.750)	25.40 (1.000)	25.40 (1.000)	12.70 (0.500)	5.56 (0.219)	6.35 (0.250)
160	50.80 (2.000)	28.57 (1.125)	31.75 (1.250)	14.27 (0.562)	6.35 (0.250)	7.14 (0.281)
180	57.15 (2.250)	35.71 (1.406)	35.71 (1.406)	17.45 (0.687)	7.14 (0.281)	7.92 (0.312)
200	63.50 (2.500)	39.67 (1.562)	38.10 (1.500)	19.84 (0.781)	7.92 (0.312)	9.52 (0.375)
240	76.20 (3.000)	47.62 (1.875)	47.62 (1.875)	23.80 (0.937)	9.52 (0.375)	12.70 (0.500)

*Bushing diameter, these chains have no rollers.

Appendix G: Production and Operational Cost of the planter

G.1.1. Materials for constructions of the planter and its cost

No	Type of material	Standard size	Unit Price	Used material	Total Price
1	Sheet metal 1.25mm	1.25x1000x2000mm	590.00	1,035,000mm^2	305.33
2	Sheet metal 2mm	2 x1000x2000mm	770.00	24,000 mm^2	9.24
3	Sheet metal 3mm	3 x1000x2000mm	1500.00	62,000 mm^2	46.50
4	Plate 5mm	5 x1000x2000mm	2175.00	38,100mm^2	41.43
5	Square pipe	30 x 30 x 3mm	350.00	4,700mm	274.20
6	Square bar	20 x 20mm	403.00	460mm	30.90
7	Angle iron	3 x 30 x 6000mm	310.00	300mm	15.50
8	Round bar	Ø8x6000mm	120.00	3,168mm	63.40
9	Round bar	Ø20x6000mm	598.00	805mm	80.20
10	Round bar	Ø25x6000mm	920.00	1,200mm	184.00
11	Circular hollow pipe	Ø34 x 6000mm	725.00	850mm	102.71
12	Circular hollow pipe	Ø25 x 6000mm	590.00	2,710mm	266.50
13	Fiyato	5x20x2000mm	600.00	600mm	180.00
14	Hinge	2.5”	10	2pcs.	20.00
15	Metal bolt and nut	M-6x20	7.50	25pcs.	187.50
16	Metal bolt and nut	M-10x300	9.00	6pcs.	54.00
17	Metal bolt and nut	M-14x300	11.00	11pcs.	121.00
18	Mofer			3,000mm	35.00
19	Erf			1,200mm	17.00
20	Electrode	Ø 2.5(pack)	130.00	1pack	130.00
21	Chain	6,000mm	600.00	520.70mm	52.07
22	Sprocket	15 teeth	400.00	1pcs	400.00
23	sprocket	30 teeth	520.00	1pcs	520.00
24	Bearing(pcs)	P206	345.00	4pcs	1380.00
Subtotal					4516.48 EB

Table G.1.2. Machine and labor costs

No.	Type of machine	Machine cost/hr	Working hour	Cost	Labour Cost/hr	Working hour	Total Price
1	Universal metal cutting	11	2.5	27.50	6.25	2.5	15.63
2	Welding machine	6	12	72	6.25	12	75.00
3	Power hack saw	4	5	20	6.25	5	31.25
4	Lath machine	15	8	120	6.25	8	50.00
5	Rolling machine manual	3.5	1	3.50	6.25	1	6.25
6	Radial drill machine	3	3	9.00	6.25	3	18.75
7	Grinding machine	1	3	3.00	6.25	3	18.75
8	Bending machine	3.5	1	3.50	6.25	1	6.25
Subtotal				258.50 EB			221.88 EB

Table G.1.3. Cost Summary

Summary of cost							
Raw material cost	Material wastage 2.5%of 1	Machine cost	Labor cost	Overhead cost 5%of (3 + 4)	Profit 10 % of (1+2+3+ 4+5)	Sells tax 15 % of (1+2+3+4 +5 +6)	Selling price (1+2+3+4+ 5 +6+7)
1	2	3	4	5	6	7	
4,516.48	112.91	258.50	221.88	480.38	559.02	922.38	7,071.55 EB

G.2 Calculation of operational cost two row animal drawn sorghum planter

The cost of operation for developed two row animal drawn sorghum planter was calculated by following procedure. The operating cost includes fixed and variable cost.

Assumptions: Yearly working hour(NAOHP) = 240

Rate of interest, I = 8%

G.2.1. Operational cost of the planter

I. Fixed cost of applicator

A). Depreciation(D_P), was calculated as follows:

$$D_P = \frac{CC - SVC}{EL}$$

Capital cost, CC = 7,071.55 EB

Salvage cost, SVC = 10% * 7,071.55 (considering 10% of Capital cost)

SVC = 707.16 EB

Assume Economic life, EL= 10 years.

$$D_P = \frac{7{,}071.55\ \text{EB} - 707.16\ \text{EB}}{10\ \text{X}\ 240\text{hr}}$$

$$D_P = 2.65\text{EB/hr}$$

B). Interest on capital (IC), was calculated as follows:

$$IC = \left(\frac{CC + SVC}{2}\right) \text{x} \left(\frac{I\%}{NAOHP}\right)$$

$$IC = \left(\frac{7{,}071.55\ \text{EB} + 707.16\ \text{EB}}{2}\right) \text{x} \left(\frac{8\%}{240\text{hr}}\right)$$

$$IC = 1.30\text{EB/hr}$$

Total fixed cost = D_P + IC

Total fixed cost = 2.65EB/hr + 1.30EB/hr

Total fixed cost = 3.95EB/hr

II) Variable cost of applicator

A). Labor wages (LW), was calculated as follows:

$$\text{LW} = \frac{\text{DLW}}{\text{DWH}}$$

$$\text{LW} = \frac{50\text{EB}}{8\text{hr}}$$

$$\text{LW} = 6.25\text{EB/hr}$$

B). Cost of repairs and spares (CRS) was calculated as follows:

$$\text{CRS} = \frac{\text{CC x } 6\%}{\text{AWHP}}$$

$$\text{CRS} = \frac{7{,}071.55\text{EB x } 6\%}{240\text{hr}}$$

$$\text{CRS} = 1.77\text{EB/hr}$$

C). Wage of oxen (WO), was calculated as follows:

$$\text{WO} = \frac{\text{DOW}}{\text{DWH}}$$

$$\text{WO} = \frac{100\text{EB}}{8\text{hr}}$$

$$\text{WO} = 12.50\text{EB/hr}$$

Total Variable cost = LW + CRS + WO

Total Variable cost = 6.25EB/hr + 1.77EB/hr + 12.50EB/hr

Total Variable cost = 20.52EB/hr

Total operational cost = Fixed cost + Variable cost

Total operational cost = 3.95EB/hr + 20.52EB/hr

Total operational cost = 24.47EB/hr

Appendix I: Photo graphs of the planter and during testing activities

Appendix Figure 1. Photographs of the planter component parts and testing activities