ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

MECHANICAL SYSTEMS AND VEHICLE ENGINEERING PROGRAM

DESIGN, FABRICATION AND PERFORMANCE TEST OF TWO ROW ANIMAL DRAWN MAIZE ROW PLANTER WITH FERTILIZER APPLICATOR

Thesis Submitted to Mechanical Systems and Vehicle Engineering Program for the Partial Fulfillment of the Requirements for the award of MSc. Degree in Agricultural Machinery Engineering

BY

Meseret Abebe

Major Advisor: Simie Tolla (Associate Prof.)
Co Advisor: Fekadu Lemessa (Associate Prof.)

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Adama, Ethiopia

CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the thesis entitled "Design, Fabrication and Performance Evaluation of Animal Drawn Maize Row Planter with Fertilizer Applicator" 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 April 2016 to February 2017 under the supervision of Simie Tolla (Associate Professor) and Fekadu Lemessa (Associate Professor), Mechanical Systems and Vehicle Engineering Program, Adama Science and Technology 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 duly acknowledged.

Name: Meseret Abebe Wakjira Signature_______ Date ____________

ADVISOR'S DECLARATION

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.

Advisor: Simie Tolla (Assoc. Prof.) Signature _______ Date ____________

Co Advisor: Fekadu Lemessa (Assoc. Prof.) Signature _______ Date ____________

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APPROVAL BY BOARD OF EXAMINERS

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DEDICATION

This thesis is dedicated to Sifrash Alemu, my mother, my mentor, my source of grace, my source of commitment and my source of knowledge; all that I am or hope to be, I owe to my angel mother for her endless love.

LIST OF ABBREVIATIONS AND ACRONYMS

A_f	Mean flat surface area
AIRIC	Agricultural Implements Research and Improvement Center
A_m	Area of the wheel calculated based on the median diameter of the wheel
ANOVA	Analysis of Variance
ANSI	American National Standard Institute
ASME	American Society of Mechanical Engineers
A_t	Mean transverse surface area of the individual seed
BD	Bulk density of the seeds
C_e	Effective field capacity
CSA	Central Statistical Agency
CV	Coefficient of Variation
d	Diameter of the shaft
D_1	Diameter of seed metering plate
D_a	Arithmetic mean diameter
DAP	Di Ammonium Phosphate
DF	Degree of freedom
D_g	Mean geometric diameter of seed
D_m	Major diameter of seed
e	Field efficiency
etc	Etcetera
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agricultural Organization Statistical database
G	Modulus of rigidity, 80.8GPa for steel
ha	Hectare
ha/hr	Hectare per hour
hr/ha	Hour per hectare
IFPRI	International Food Policy Research Institute

J	Polar moment of inertia.
K_b	Combined shock and fatigue factor applied to bending moment
Kg	Kilogram
kg/cm^2	Kilogram per square centimeter
Kg/ha	Kilogram per hectare
Kgf	Kilogram force
K_t	Combined shock and fatigue factor applied to torsional moment
L	Mean Length of seed
LSD	Least Significant Difference
m	Number of cells on plate
MARC	Melkassa Agricultural Research Center
M_b	Bending momentum
M_h	Horizontal bending momentum
MISI	Miss index
MoARD	Ministry of Agriculture and Rural Development
MS	Mean Square
$m\ s^{-1}$	Meter per second
MT	Metric Ton
M_t	Torsional moment
MULI	Multiple index
M_v	Vertical bending momentum
N	Speed of the shaft
n	Number of refilling per hectare
P	Power required to driving the machine
P_p	Plant population per hectare
PREC	Precisions
P_s	Plant spacing
QTFI	Quality of feed index
R_i	Inner radius of the wheel
r_m	Median radius of the wheel

R_o	Outer radius of the wheel
S_m	Mean sphericity
S_{mf}	Mean forward speed
SR	Seeding rate
SS	Sum square
S_s	Allowable stress
T	Mean thickness of seed
t	Distance between consecutive cells
t ha^{-1}	Ton per hectare
T_e	Effective operating time
T_t	Total time
t_w	Thickness of the wheel wall
USA	United States of America
USDA	United States Department of Agriculture
USMARC	University of Southern Mindanao Agricultural Research Center
V	Mean volume
W_e	implement effective width
W	Mean width of seed

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ABSTRACT

This study focused on the design, fabrication and performance evaluation of a two row animal drawn maize planter that is cheap, easily affordable by the farmers, easy to maintain and less laborious to use. The planter consists of the main frame, handle, seed and fertilizer hopper, seed metering device, adjustable furrow opener, adjustable furrow closer, drive wheels, seed tube and ball bearings. Most of these were fabricated from mild steel material. The planter is simple to use, the various adjustments are made with ease, and it is maintenance free, except for the bearings which needs to be lubricated. Physical properties of maize seeds were investigated to optimize the design of the planter's components. The performances were evaluated in terms of percent seed miss index, percent seed multiple index, percent quality seed feed index, percent seed precision index, depth of planting, plant count/stand, field capacity, field efficiency, labour cost and economics of owning and operating. The experimental design used was factorial design. The result showed that the sphericity of seed, percent of visible mechanical seed damage and mean percent of seed germination were 71.56±7.10%, 1.01± 0.37% and 94.58±0.21 respectively. The analysis revealed that the forward operational speed of the planter had significant effect on percent seed miss index, percent seed multiple index, percent quality seed feed index and percent seed precision index at $p < 0.05$. The mean field capacity, field efficiency and depth were 0.21 ha/hr, 86 % and 4.6± 0.3 cm respectively. The cost of fabrication for the development of the planter was 8,053 Birr. *Based on the performance evaluation results, it is concluded that the prototype planter was easy, efficient and affordable by maize producing farmers of Ethiopia.*

1. INTRODUCTION

1.1. Background and Justification

Maize (*Zea mays* L.) is an important grain crop of the world and it ranks second, after wheat in hectarage (177,379,567 ha) and first in total production (872,066,770 MT) and productivity (4.9 t ha^{-1}) (FAOSTAT, 2013). Maize is recognized worldwide as a strategic food and feed crop that provides an enormous amount of protein and energy for humans and livestock. Its advantages in the ethanol industry also keep maize in high demand. Although much of the world's maize production is utilized for animal feed, human consumption in many developing and developed countries is steadily increasing. It is the most important cereal crop for food in Sub-Saharan Africa and Latin America. Between 2010 and 2050, the demand for maize in the developing world will double, and by 2025, maize is likely to become the crop with the greatest production globally (Rosegrant *et al.*, 2010).

Maize has expanded rapidly and transformed production systems in Africa as a popular and widely cultivated food crop since its introduction to the continent around 1500 A.D. (McCann, 2005). Maize arrived in Ethiopia slightly later, around the late 17th century (Huffnagel, 1961), and was mainly grown as a subsistence crop in the mid-altitudes in southern, south-central, and southwestern parts of the country. Maize production and its status in determining food security in the country received a major focus in the mid-1980s, particularly spurred by the 1984 devastating drought and the famine that followed. The wide adaptability of the crop and the potential to produce more calories and food per area of land cultivated than all major cereals grown in Ethiopia were important factors in considering maize as part of the national food security strategy, including its inclusion under the government-led intensive agricultural extension program (Abate *et al*., 2015).

In Ethiopia, maize grows under a wide range of environmental conditions between 500 to 2400 meters above sea level. Even though Ethiopia has many agro-ecologies, maize growing areas can be classified into four broad maize agro-ecologies namely; mid-altitude sub-humid, low moisture stress areas, high altitude sub-humid and low altitude sub-humid. The mid-altitude and lowland sub-humid agro-ecologies are the high potential areas for maize production and contribute the largest proportion of maize grain in the country. The high altitude sub-humid, including highland transition and true highland, is next to mid-altitude in maize area and production in Ethiopia.

The total proportion of the maize to all the major crops is 25% in production (CSA, 2014). The per capita consumption of maize in Ethiopia is about 55 kg; however, the level of consumption varies from place to place. Although there is a remarkable increase in maize yield starting from late 1990s, it is still very low as compared to developed countries and the world average yield (5.5 t ha^{-1}). According to FAO 2013, for example, the national average grain yield for USA is 9.97 ton ha^{-1}, Canada 9.59 ton ha^{-1}, German 8.83 ton ha^{-1}, China 6.02 ton ha^{-1} and world average is 5.5 ton ha^{-1}.

Over half of all Ethiopian farmers grow maize, mostly for subsistence, with 75 % of all maize produced being consumed by the farming household. Currently, maize is the cheapest source of calorie intake in Ethiopia, providing 20.6 % of per capita calorie intake nationally (IFPRI, 2010). In maize producing areas, it is staple food and in areas where it is not staple, it is used mixed with other food grains. It is also used for making local beverages. Additionally, the leaves are used to feed animals and the stalks are used for construction and fuel. A small quantity of the grain produced is currently used in livestock and poultry feed, and this is expected to increase with the development of the livestock and poultry enterprises in the country. The green fodder from thinning and topping is an important source of animal feed and the dry fodder is used during the dry season. Moreover, the crop has potential uses for industrial purposes, serving as a starch, a sweetener for soft drinks, an input for ethanol fuel production and oil extraction, etc. As compared to other cereals, maize can attain the highest potential yield per unit area. Maize is thus an important crop for overall food security.

The production and productivity of maize in all agro-ecologies are constrained by several biotic and abiotic stresses even though the importance of the constraints varies from agro-ecology to agro-ecology and from location to location within the same agro-ecology. Despite all the efforts and progresses made so far in development and dissemination of improved maize technologies for different agro-ecologies, different biotic and abiotic constraints still remain the major limiting factors for maize production and productivity. Hence, continuous development and popularization of better performing maize technologies in each agro-ecology has paramount importance for sustainable maize production.

The status of agricultural mechanization in the production line of maize, such as land preparation, planting, harvesting, threshing, milling and storage is very low. Almost all of the farm operations are performed with bare hand or using rudimentary hand tools and traditional animal drawn implements (MoARD, 2010). From those major mechanization problems, it was mentioned by MoARD (2010) that planting method is one; it was believed that this problem was created due to lack of suitable planters throughout the country. Maize farmers normally use hand-broadcasting method for planting maize seeds on the field. It is obvious that this traditional method of planting is time consuming, distributes the seed non-uniformly and cannot maintain the optimum plant density in the field. As a result, low efficiency and high cost are being incurred throughout the system. Furthermore, hand broadcasting requires experienced manpower to broadcast the seeds in order to get optimum plant population.

1.2. Statement of the Problem

In general broadcasting of maize has been done by hand in most maize growing areas of Ethiopia; this leads to low yields of maize per hectare and high cost of production. The causes include:

- Lack of suitable row planting machine for direct seeding application in rows.
- Wastage of time, money, improved seed and labor as the amount of hand broadcasted was higher, which resulted non optimum plant population, uneven distribution, and hence difficult to use mechanical cultivator. Therefore, weeding manually rise the production cost higher than the expected productivity of the crop.
- Required higher man-hr/ha to plant in rows by hand.

1.3. Objectives

1.3.1. General objective

- To design, fabricate and evaluate the performance of low cost, efficient and suitable animal drawn maize precision planter.

1.3.2. Specific objectives

i. To find the physical properties of maize seeds related to maize row planter
ii. To design and fabricate animal drawn maize row planting machine
iii. To evaluate the performance of the row planter

1.4. Significance of the Study

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). It is very difficult for these farmers to own and operate costly agricultural machinery and equipments that can establish the optimum plant population. However, most of Ethiopian farmers have draught animals that can be used as the cheapest sources of draught power for agricultural operations. Hence, developing animal drawn maize planters, which are robustly built, reliable, economical and simple to use and transport, are important to reduce the problems discussed above.

In this study, effort was made to solve problems observed in traditional maize planting method through design and fabrication of technically and economically compatible animal drawn two row maize planter with fertilizer applicator.

2. LITERATURE REVIEW

As Kepner *et al*. (1978) point out, the primary objective of any planting operation is to establish an optimum plant population at optimum plant spacing, with the ultimate goal being to obtain the maximum net return per hectare. Population and spacing requirements are influenced by such factors as the kind of crop, type of soil, the fertility level of the soil, the amount of moisture available, and the effect of plant and row spacing upon the cost and convenience of operations such as thinning, weed control, cultivation, and harvesting. For many crops there is a fairly narrow range of plant populations that will give the maximum yield under a particular set of conditions.

Once the optimum plant population has been determined and the method of planting selected for the specific crop, the next main consideration is plant spacing. For broadcast crops the mean plant spacing is determined by the plant population, but for row crop planting the row and in-row spacing have to be selected. The selection of row and in-row spacing is based on a compromise between acceptable access to light, moisture and nutrients, and the mechanisation requirements. Most crops can tolerate moderate variations in uniformity of in-row plant spacing without seriously affecting yield, providing the average population density is within the optimum range.

Spacing of plants within a row will changes the degree of competition between neighboring plants that in turn can alter the amount of nutrients available to a plant. Uniform spacing between plants will increase yield due to reduced plant competition among closely spaced plants (Nielson, 2001). Workers evaluated within row plant spacing using a conventional planter with controlled seed disks that altered inter-plant spacing. Yield decreased at a rate of 106.7 kg ha^{-1} per 2.54 cm increase in standard deviation of plant spacing. Supporting observations were reported by Liu et al. (2004c) who compared three different types of conventional maize planters where planter type (finger pick-up, air seeder, and vacuum meters) had different spacing of plants within a row. In contrast to these findings, Liu et al. (2004a) found no significant decrease in grain yield from increasing the within-row spacing of maize plants in hand planted plots. Presumably, inter-plant competition will be altered not only by spacing within a row but also by inter-row spacing and plant density within a row, e.g., total plant population.

As planting populations increase, competition for resources among plants will increase. Porter *et al*. (1997) observed greater yields during a dry growing season when planting populations were decreased. When density of plants increases, stalk lodging will increase due to smaller stalk diameter (Widdecombe and Thelen, 2002). These researchers observed that the number of lodged stalks increased as plant population increased to 90,000 plants per ha^{-1}.

Maize grain yield is the multiple of the number of fertilized developing kernels on the plant and weight per kernel (Duncan, 1975). The maximum number of kernels that a maize plant can produce is determined at or slightly after pollination; once pollination has occurred, the plant cannot produce more kernels (Duncan, 1975). As plant population increased, Maddoni et al. (2006) observed that yield and kernel numbers increased but weight of kernels decreased. Similar results were observed by Porter et al. (1997), who observed a decrease in kernel weight as population increased in field based experiments. Contrary to these findings, Widdecombe and Thelen (2002) observed slight increases in grain test weight as plant population increased.

Under intensive cropping, timeliness of operations is one of the most important factor which can only be achieved if appropriate use of agricultural machines is advocated (Salokhe and Oida, 2003). With the present day advanced agronomic practices, seed genetics and on- farm technology to deliver optimal yield while using fewer resources, precision planting is not out of place. Manual method of seed planting, results in low seed placement, spacing efficiencies and serious back ache for the farmer which limits the size of field that can be planted. Hand-pushed and tractor mounted row seeders (usually single and multiple row) normally requires a well prepared seed-bed which may be ridged or flat bed.

Precision planting was pioneered as the placement of single seeds in the soil at the desired plants spacing (Datta, 1974). Usually, plant scientists use hand dibblers to achieve this degree of accuracy. Sowing devices equipped with single seed metering devices are called precision planters. The first developed precision planters were horizontal plate planters with cells on the periphery.

Seeds drilled by precision planting are sown with optimum row and within-row spacing depending on the seeding requirements for each specific crop (Bracy *et al*., 1998). Plant spacing can affect both vegetative and reproductive growth and yield and is directly related to seed spacing uniformity.

Various types of precision planter designs have been developed with different design approaches which have their advantages and disadvantages and also operational limitations. Singh (1984) designed and developed a two-row tractor drawn ridge planter for winter maize. The inclined plate metering mechanism was mounted on a commonly used three bottom ridge. The planter was tested in laboratory as well as in the field. Laboratory tests showed that 50 seeds could be delivered in a strip of 10 m maintaining recommended seed-to-seed spacing of 20 cm. However, the results varied in the field test.

Lara *et al*. (1996) developed a single-row direct planter for maize. The planter may be attached to a walking or riding type two-wheel tractor. The planter performance was in accordance with the recommended plant population for maize.

The single and double row planters developed at the University of Southern Mindanao Agricultural Research Center (USMARC) can plant a hectare within 6-8 hours for single-row and half so much time for double-row. The equipment can plant, fertilize, and cover the seeds and fertilizer in one operation. The use of this planter in maize production substantially reduces cost of production by as much as 25 to 30%, because furrowing, planting, and fertilizing are done simultaneously (Sarmiento, 1997). However, the machine cannot be operated without a draft animal.

Bamgboye *et al*. (2006) tested a manually operated two row okra planter developed from locally available materials. The planter had a field capacity of 0.36 ha/h with a field efficiency close to 72%. The laboratory tests gave better spacing results than under field tests due to clogging of seeds and germination failure.

Goncalves *et al.* (2010) carried out to evaluate the influence of the combination of displacement speed and the load applied by the compacting wheel of a seeder fertilizer machine on the emergence of the seedlings and initial development of the maize crop in the no-till system. The study was done with the use of three displacement speeds of the seeder machine (1.11, 1.67 and 2.22 m s^{-1}) in combination with four loads applied by the compacting wheels (119.26, 131.11, 257 and 339 N). The load of 339 N caused a lower seed deposition depth than the load of 131.11. The maximum flattening of soil layer on the seed occurred with the load of 339N, due to the pressure exerted by the compressing wheels. There was no interaction between the factors, as well as no significant difference between the evaluated speeds. The load applied by the compressing wheels and the displacement speeds used for seeding had no influence on emergence and initial establishment of the maize crop.

A disc type maize seeder developed which is simple in design and can be handily operated with ease and comfort (Rolando *et al*, 2011). It requires a pre-established furrow and after the falling of seed they are covered by soil. This is a labor intensive and time consuming process.

Most Ethiopian farmers have been using the method of broadcasting seeds and fertilizers and covering by *maresha* for a long time. Broadcasting is not suitable method of planting for different kinds of crops as it does not ensure desired plant population. The spacing will not be uniform and hinders intercultural practices, which contribute to lower yield.

In 1995, engineers at MARC designed the first row planter as an attachment to the indigenous *maresha* plow to enable farmers to plow and plant crops in rows (as opposed to broadcasting). The original row planter was first brought to the field in 1996 after a farmer from the Wolencheti Peasant Association had expressed interest in testing the technology after he had visited MARC to observe the new technologies being developed (Abra K Adam, 2001).

Agricultural Implements Research and Improvement Center (AIRIC) conducted a research on different planting implements to obtain optimum plant population and spacing. Precision seed metering devices were collected, tested and evaluated both in the laboratory and field (Table 2.1). The planters were tested for maize, sorghum and haricot bean using different seeding plates prepared for these crops. The earth way planter was found better in terms of time compared to wheel hoe and Hassia planter. The test result conducted showed that the draft requirement was found to be on the average 87.9 Kgf (Kilogram force) and the field capacity was 0.1 ha/hr., when used with covering device, which is adjustable between 4cm and 7cm. The planter worked effectively in different types of soils, in muddy and cloddy fields as its metering mechanism did not depend on ground wheels (AIRIC progress report, 1992, unpublished). During extensive testing on farmers' fields the row planter has shown many advantage over the traditional practices. But it has certain limitations like the metering mechanism is operated by the plow man himself simultaneously while goading the animals thus this makes the operation more difficult. The second and the most important part of the problem was the manufacturing aspect is not simple and hence the cost of production is high. Therefore, further improvement work has to be carried out. As can be seen from the table below their performance test data were not that much satisfactory, leaving a room for further work (Table 2.1). Even Crop emergency of American made single row garden planter is about 22.4% and that of Japan made single row precession planter is about 12.6%.

Fitsum (2014) designed, developed and evaluated animal drawn maize-cum-fertilizer planter. Its performances in seed metering and uniformity of applications were found to be closer to the seed spacings and uniformity which can be achieved by employing manual planting. It also saved time in performing planting operation when it was compared with the sweeper attached planter and the conventional method of seed sowing in rows. Its seed damage and draft requirement were also found to be insignificant.

Ashebir (2015) developed animal drawn multi crop planter that can plant Maize, haricot bean and sorghum. The mean field capacity, field efficiency and depth were 0.12 ha/hr (8.33 hr/ha), 71% and 4.94cm with coefficient of variation of 0.042 (4.20%), respectively. Percent of visible seed damage by the planter were insignificant. Germination tests conducted to assess the magnitude and extent of invisible seed damage inflicted by the planter indicated mean percent seed germination of 97.38, 83.61 and 80.46 for maize, haricot bean, and sorghum, respectively.

Table 2.1. Field and lab result of some row planters found in MARC.

Type of planter	Type of seeds	Lab result (kg/ha)	Field result (kg/ha)	Time (hr/ha)	Cone penetrometer resistance(kg/cm^2) at 15cm	Soil moisture (%)
AIRIC made *erf* & *mofer* attached planter (animal drown)	Maize	-	92	7	0.03	15.6
	Bean	-	110	12	0.03	15.6
AIRIC made six row wheat planter (animal drawn)	Wheat	259	140	4	0.026	15.95
Japan made single raw garden planter	Maize	9.2	8.45	227	0.008	15.16
American made single raw garden planter	Maize	58.1	53	222	0.008	15.16

Source: AIRIC progress report 2012, unpublished

3. MATERIALS AND METHODS

3.1. The Experimental Site

The fabrication and performance test of the machine were conducted at Melkassa Agricultural Research Center. It is found around 117 km South East of Addis Ababa along Sodere road. It is located at an altitude of 1466m above sea level and lies on the geographical coordinates of 8° 24' 0'' N, 39° 20' 0'' E Latitude and Longitude respectively. It has a highly variable rainfall that ranges between 500 and 800 mm annually. The dominant soil type in the area is sandy loam. Because of its agro-climatic condition, most varieties of maize crop grow well in the area.

3.2. Physical Properties of Seeds

3.2.1. Length, Volume and Sphericity

Seed properties are important factors for optimizing the parameters of the design of seed planter. Mohsenin (1986) reported that the physical properties of any material such as shape, volume, and surface area are important in many problems associated with design or development of specific machine or analyzing the behavior of the product in handling or grading of the material.

Physical properties of maize seeds were determined by randomly selecting 100 maize seeds from the representative samples and measuring their three principal diameters using a digital caliper of 0.01 mm accuracy. The larger, intermediate and minor diameters of the seeds were designated as length, width and thickness, respectively. The mean sizes of the seeds were determined as geometric mean diameters. The mean geometric diameter, mean volume and percent mean seed sphericity of maize seed were calculated as (El-Raie *et al.*, 1996);

$$D_g = \sqrt[3]{LxWxT} \quad (3.1)$$

$$V = \frac{\pi}{6}(LxWxT) \quad (3.2)$$

$$S_m = \frac{D_g}{L} = \frac{\sqrt[3]{LxWxT}}{L} x100 \quad (3.3)$$

Where: - L = mean length (mm)

W = mean width (mm)

T = mean thickness (mm)

V = mean volume (mm^3)

D_g = mean geometric diameter (mm)

S_m = Percentage of mean seed sphericity

3.2.2. Bulk Density

The bulk density was determined by putting maize seeds in a cylindrical shaped container. The volume of the containers was found by measuring diameter and height of the container. The weight of the grain in the container was found separately and the bulk density was calculated as;

$$\rho_{bulk} = \frac{m}{V} \quad (3.4)$$

Where: - $\rho_{bulk} =$ bulk density of maize seed, kg/m^3

m = mass of the seed, kg

V = height of cone, m^3

3.2.3 Thousand Seed Weight

One thousand maize seeds were randomly taken and weighed to obtain thousand seed weight.

3.2.4 Angle of Repose

Maize seeds were piled and allowed to fall vertically to form a natural inverted cone. The height of the inverted cone was measured. The angle of repose is the angle between the base and the slope of cone formed on a free vertical fall of the material to a horizontal plane.

The angle of repose was calculated using the following equation,

$$\theta = tan^{-1}(\frac{2H}{D}) \quad (3.5)$$

Where: - θ = angle of repose, degrees

H = height of cone, cm

D = diameter of cone, cm

3.3. Description, Design Analysis and Material Selection of Major Components of the Prototype Planter

The prototype planter is two row animal drawn (donkey drawn) maize row planter with fertilizer applicator designed to serve as an intermediate technology between the hand tools and the tractor drawn row planters. It consists of seed and fertilizer hoppers, metering mechanisms, furrow openers, furrow covering devices, frame and drive wheels.

To operate it, seeds are poured into the hopper; the planter is then positioned at the desired starting point, and pushed along the row. About two seeds are picked up by the metering plate and introduced into the chute. The furrow opener continuously opens the soil and the seeds metered into the chute fall into the opened furrow which are simultaneously closed by the furrow closer. As the planter is pushed along the row, it continuously places seeds at 25 cm intra row spacing and 70 cm inter row spacing (USDA recommended spacing for maize), until the seeds in the hoppers are finished to a level requiring refilling of the hoppers.

The machine was designed based on the agronomic nature of the crop, the soil type and characteristics of the place on which the machine works, the speed and draft capabilities (performance) of the pulling animals and also the financial capacities of the end users. To lower the cost of production and for ease of operation, the construction materials used were light but durable and also optimum in cost. Data that were important for designing the machine components, such as agronomic data and draft performance of the pulling animals, were collected prior to designing. To achieve the best performance from the planter, the important factors were optimized by proper design and selection of the components required to suit the requirements of maize seeds.

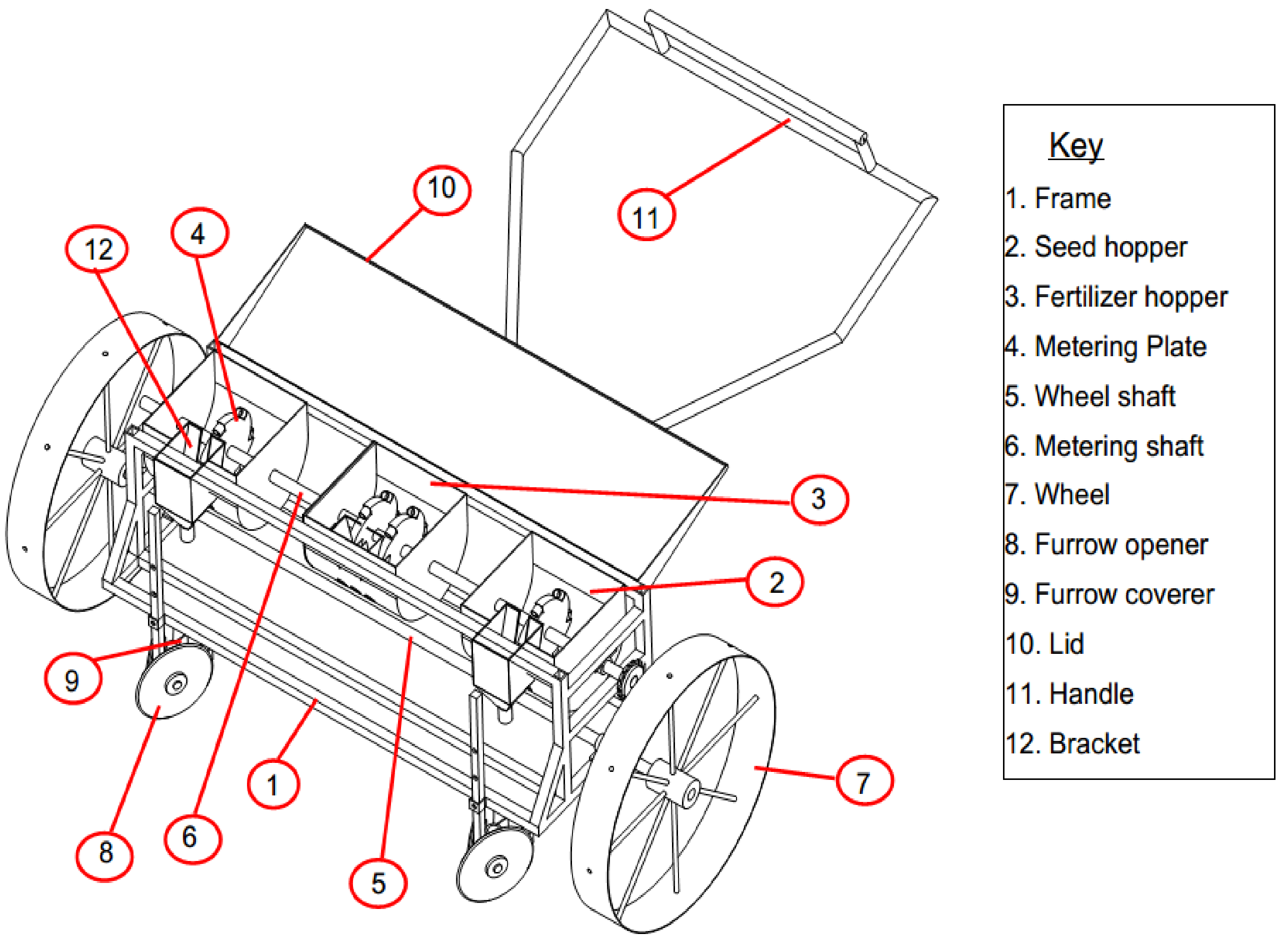

Fig. 3.1 Major components of the prototype planter

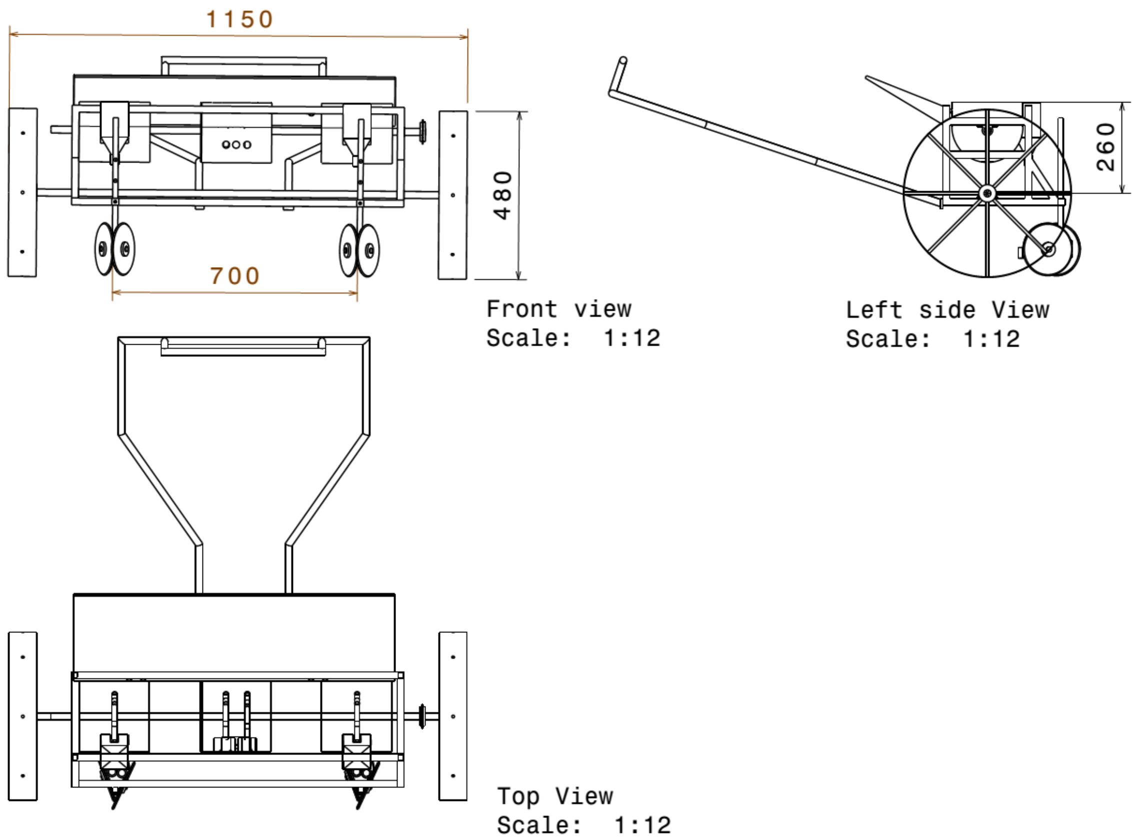

Fig. 3.2 Third angle projection of the planter

3.3.1. Main Frame

The frame is the skeletal structure of the planter which forms the platform on which other components are mounted. It was subjected to torsion and bending due to induced draft. Design was based on the stresses produced in the frame. The material of the main frame was selected based on achieving a reasonable weight and required strength. A square hollow pipe bar of 20 mm x 20 mm mild steel was used to give the required strength and rigidity, so that it can withstand all types of load during operation.

The frame and other component parts of the planter were connected using appropriate sizes of bolts, nuts and holes. During the design and fabrication of the frame, provisions were made to fix adjustable furrow openers at 70 cm spacing, i.e. the spacing between two rows. The design of the frame was also based on the design of components to be mounted on it (See Fig. 3.3).

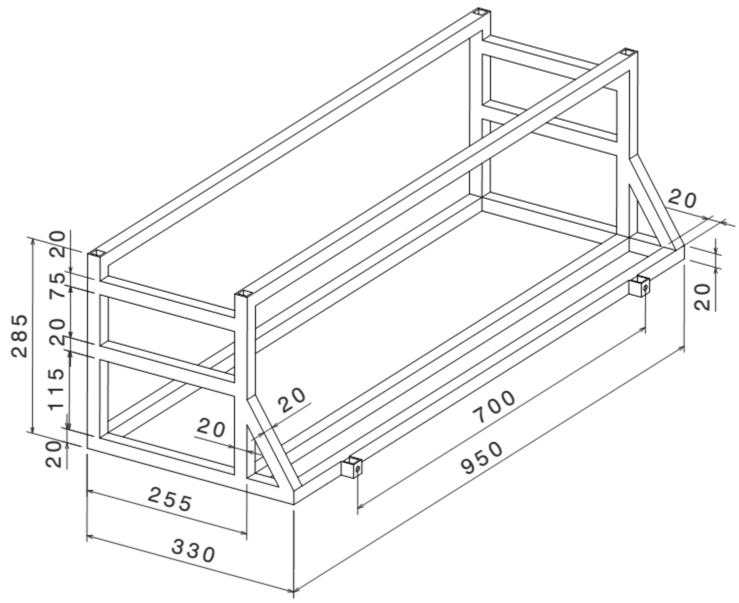

Fig. 3.3 Main frame material

3.3.2. Design of Seed and Fertilizer Hopper

The hopper is a device in which the seeds to be planted are kept before their gradual release into the furrowed tunnel. The amount of seed and fertilizer contained depends upon the size of the seed hopper. To reduce maintenance costs, the hopper designed has three separate boxes mounted on the frame; two outer boxes for seed and one inner box for granular fertilizer. They are made from the same material and have equal dimensions. The material used for the construction was mild steel sheet metal with thickness of 1.25 mm, which is readily available in market and relatively affordable. The hopper also has a lid, with a handle on top to ease opening. The shape and dimensions of each hopper compartments are shown in Figure 3.4.

The hopper is a gravity discharged hopper designed to ensure proper flow of seeds and fertilizer by the action of gravity only. The recommended side slopes of gravity discharged maize hopper at a moisture content of 15%, were 28^0 (Waziri and Mittal, 1983). To ensure free flow of maize seeds, a circular curvature side slope was selected.

In the design of hopper capacity, seeding rate of 42 kg/ha for maize was considered; and the bulk density of maize at a seed storage moisture content of 15%, was considered as 720 kg/m^3 (Waziri and Mittal, 1983). Equation given by Olaoye and Bolufawi (2001) was used to estimate the volume of the hopper as follows:

$$V = \frac{S_R}{\text{nx BD}} \qquad (3.6)$$

Where: - S_R = seeding rate (kg/ha)

n = number of refilling per hectare (let, 10 times)

BD = bulk density of the seeds (kg/ m^3)

$$V = \frac{42\frac{kg}{ha}}{nx720\frac{kg}{m^3}} = \frac{42Kg/ha}{10/ha*720\ kg/m^3} = 5.83x10^{-3}\ m^3$$

The maximum volume of the designed hopper is:

$$Volume = [200\text{x}200\text{x}70] + \left[\frac{\pi\text{x}200^2}{8}\text{x } 200\right] = 5.94\text{ x}10^{-3}\text{m}^3$$

Since the designed hopper volume is higher than the theoretical volume, it can accommodate the seed and fertilizer.

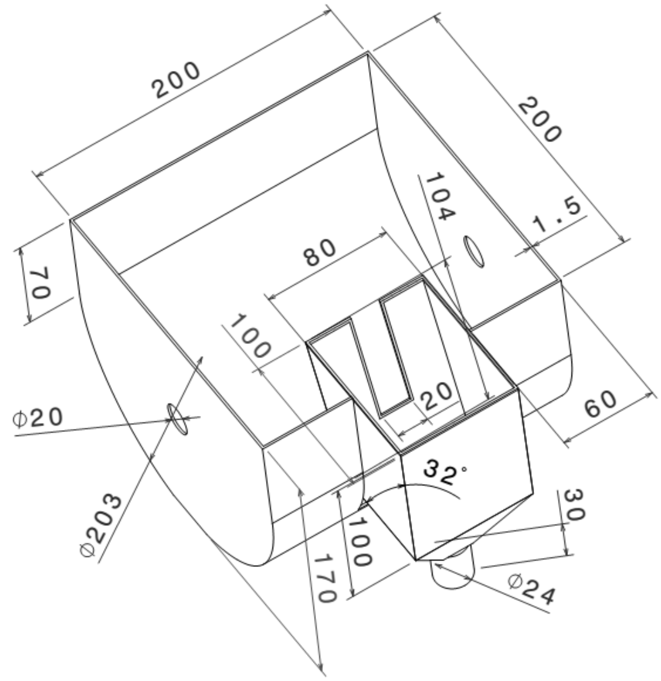

Fig. 3.4 Isometric view of seed hopper

3.3.3. Design of Seed Metering Device

Metering mechanism is the heart of a planting machine and its function is to distribute seeds uniformly at the desired application rates. The seed rate and seed spacing are adjusted by metering device. The performance of a planter depends much upon right calibration of metering device. Horizontal seed metering devices were popular and widely accepted but problems occurred with higher seed damage, seed missing and multiple drops. To reduce these losses, inclined and vertical plate planters were developed (Shafii and Holmes, 1990).

The metering devices were made from mild steel vertical discs with six cups/scoops on the periphery. Cup feed mechanism was used so that there should not be mechanical damage due to mechanical handling. A series of cups were fitted on the rim of a vertical rotating plate that dips into a seed hopper, lifting two seeds at a time and carrying them over a top, where they are dropped into a delivery channel. The cells on the periphery were spaced to give the required seed spacing between plants. To attain uniform seed measurement at different speeds, brackets were used as a guide in seed metering plates. The brackets collect the seeds thrown at different speeds and deliver to seed delivery channel. The ground wheel, through the driving shaft, provided the desired torque to drive the metering devices, which were in turn mounted and locked in place on the second driven metering shaft.

The size and number of cups were determined depending on the mean size and shape of maize seeds, desired rate of planting, recommended intra-row spacing of maize seeds, and economical and efficient size (diameter) of driving wheel. The dimension/diameter for Melkassa-138 maize variety varied between 8.0 mm and 12.5 mm. The cells to meter maize had 15 mm diameters and 15 mm depth. The number of cells and distance between consecutive cells on the seed metering roller were obtained using the following expressions (Sharma and Mukesh, 2010);

$$n = \frac{\pi D}{i.X} \qquad (3.7)$$

$$n = \frac{\pi\, x\ 47.75\ cm}{1\ x\ 25\ cm} = 6$$

Where: - n = number of cells on a roller (minimum value)

D = Diameter of ground wheel (47.75cm)

i = gear ratio (1:1)

x = required seed to seed spacing

$$t = \frac{\pi D_m}{n} \qquad (3.8)$$

$$t = \frac{\pi x\ 14\ cm}{6} = 7.33\ cm$$

Where: - t = distance between consecutive cells

D_m = Diameter of seed metering roller

n = number of cells on a roller (minimum value)

Therefore, the number of cells is 6 and distance between consecutive cells is 7.33 cm.

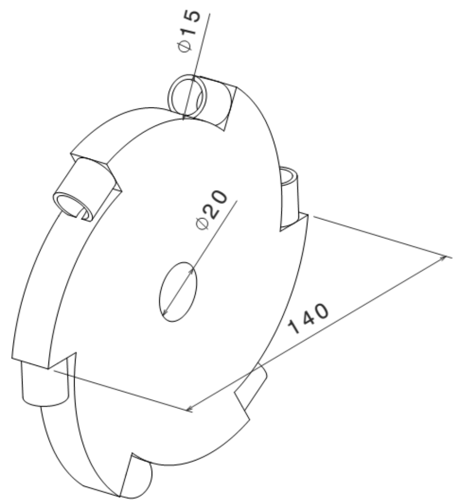

Fig. 3.5 Isometric view of seed metering plate

3.3.4. Design of Fertilizer Metering Device

The fertilizer metering mechanism was designed for use of granulated fertilizer. It takes power from ground wheel by chain drive and rotates the fertilizer metering shaft. The fertilizer metering mechanism was designed for spot dropping of fertilizer at a distance of 50 mm from a seed. The recommended DAP (Di Ammonium Phosphate) fertilizer application rate for maize is 100 kg/ha (Regional Agricultural Bureau extension program manual 2006). However, the fertilizer delivery rate depends on soil condition. The fertilizer metering plate had the same size and number of cells to that of seed metering plate.

3.3.5. Design of Furrow Opener

Furrow openers are parts of a planter that are used to open furrow so that seed is placed at a specific depth below the surface. The design of furrow openers of seed planters varies to suit the soil conditions. Adjustable double disc type furrow openers were designed to avoid seed rebounding, to roll over obstacles and to improve seed placement accuracy at different planting depth. Disc type furrow openers are suitable for use when penetration through crop residues or into hard ground is required. In wet, sticky soils they are more satisfactory than fixed openers because they can be kept reasonably clean. Double disc furrow openers are particularly well adapted to medium or shallow seeding of row crops that are critical in regard to planting depth, because the depth can be controlled accurately with removable depth bands (Elliot, 1994). The discs of the furrow openers were fabricated from 6 mm thickness mild steel sheet metal with 70 mm diameter. The discs were chamfered throughout the circumference to have sharp edge and arranged at an angle in which one disc leads the other.

One end of the shank was fitted with double disc type furrow openers and the other end with the frame by nuts and bolts. The dimensions of the shank were estimated on the basis of the design below.

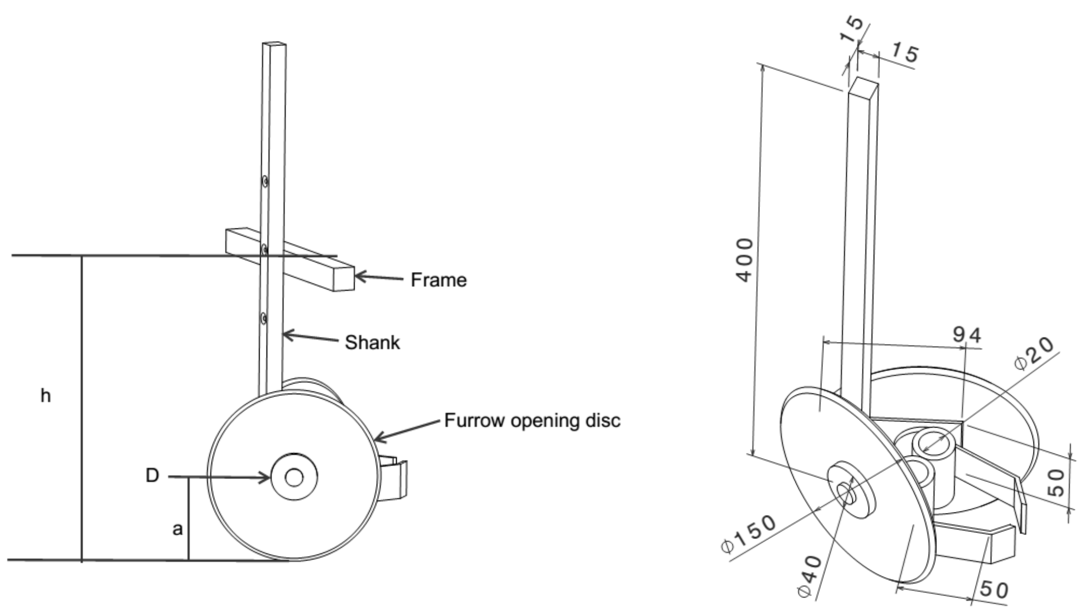

Fig. 3.6 Parts and dimensions of furrow opener

In the design of the furrow opener, the pull performance of a donkey was considered. According to Kefyalew (2014), the resultant pull force performance of the donkey is 475.39 N. It was assumed that the draft force was applied to the two furrow openers of the planter; 238 N on each (24 kgf/ furrow opener).

Distance of draft application on furrow opener tyne is (Sharma and Mukesh, 2008);

$a = h/3$ ……………………………………….....………. (3.9)

= 250 / 3

= 83.33 mm

Moment arm length = (h-a) ………………………………...........…. (3.10)

= (250 – 83.33) = 166.67 mm

Bending moment in shank = D (h-a) ……………………….........…. (3.11)

= 24 × 166.67 mm

= 4000 Kg.mm = 400 Kg.cm

= 400 Kg.cm × 9.81 N/Kg× 10 mm/cm

= 39,240 N mm

Take factor of safety = 2

Therefore, the maximum bending moment in the shank (tyne) = 39,240 N mm × 2 = 78,480 N mm

The section modulus of the shank can be computed from the following equations,

$Z = Mb / fb$ …………………………..………..…....…. (3.12)

= 78,480 N.mm / 56

= 1401.4 mm^2

Where: - h = Total length of furrow opener and tyne /shank (taken as 250 mm)

D = Draft force on furrow opener, 24 kgf

a = Distance of draft application on furrow opener tyne

Mb = maximum bending moment, N-mm

f_b = bending stress (56 N/ mm^2 for mild steel)

Z = section modulus of tyne, mm^3

t = thickness of flat, mm

b = width of M.S flat, 35 mm (available in the market)

$$Z = \frac{1}{6}\, tb^2 \qquad (3.13)$$

$$t = 6x1401.4\ \text{mm}^2/(20\text{mm})^2$$

$$= 6.86\ \text{mm}$$

Therefore, a Mild steel flat tyne of 35x6mm size was used.

3.3.6. Adjustable Furrow Covering

To achieve optimum germination and emergence results, planters should be designed to pack the soil, press the seeds into the compacted soil, and cover the seeds with loose soil. Increasing seed/soil contact below and around the seed improves capillary continuity between the lower moist soil layers and the upper layers in which the seed is planted, and between the seed and soil immediately surrounding it. Leaving the soil immediately above the seed row loose minimizes crusting and promotes easy emergence. The designed furrow covering devices 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 3 mm thickness positioned immediately at the back of the furrow opener (Fig. 3.7).

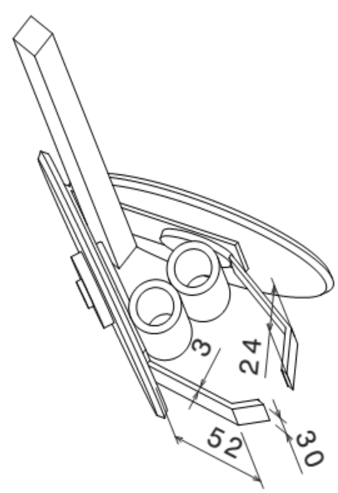

Fig. 3.7 Isometric view of furrow covering device

3.3.7. Seed Tube

Seed tube is the channel through which seeds are conveyed to the furrow. The seed discharge spout/tube is welded at an angle to the hopper and connected to a short pipe through which the seed is guided into the furrow bottom and deposited. The material used to construct the discharge spouts was mild steel sheet metal with thickness of 1.50 mm. The outlet diameter is 20 mm.

3.3.8. Handle

Handle is used to provide the push force from a human operator to move the planter from one point to another during planting operation. The handle was made from mild steel circular hollow pipe. It was designed with two different gripping ends to suit the average standing elbow height of female operators. The length and diameter of the handle is 36.7 cm and is 20 mm respectively (Fig 3.11).

3.3.9. Row Marker

The function of the planter row marker is to help the operator maintain a more accurate row spacing. A constant crop row spacing helps for making simpler and more effective cultivation especially when cultivating between rows. Before planting of any type of crop, consideration should be given to the subsequent cultivation operation. It was made of plated steel.

3.3.10. Stand

When the operator completes the work in the field or gets tired, then it is necessary to put up the planter for taking rest. It was made from mild steel solid rod of 250 mm length and 10mm diameter.

3.3.11. Weight Determination of Components 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 and seed tubes, and seeds in the hopper were estimated using appropriate equations.

3.3.11.1. Weight of the Hopper

Figure 3.8 shows the hopper used on the planter. Since the seed and fertilizer hoppers have equal dimensions and made from the same material, the weight of the single hopper was estimated and used for the rest two hoppers.

$$A_{HM} = 2\left((ABxAC) + \left(\frac{\pi x D^2}{8}\right)\right) + \left(AC + BD + \frac{\pi D}{2}\right)(FG) \ldots\ldots\ldots\ldots\ldots \text{(3.14)}$$

$$A_{HM} = 2((200x70) + \left(\frac{\pi x 200^2}{8}\right)) + \left(70 + 70 + \frac{\pi x 200}{2}\right)(200)$$

$$= 150{,}247.78mm^2 = 0.15m^2$$

$$V_{HM} = A_{HM} x t_{HM} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.15)}$$

$$= 0.15m^2 X 1.5 X 10^{-3} m = 2.25x10^{-4}\, m^3$$

$$M_{HM} = V_{HM} x \rho_{\,HM} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.16)}$$

$$= 2.25x10^{-4}\, m^3\; x7850\, {}^{Kg}/_{m^3} = 1.766\, Kg$$

For the three hoppers, i.e., two seed hoppers and one fertilizer hopper, we have:

$$M_{HM} = no.\,hoppers\; x\; V_{HM} x \rho_{\,HM} = 3x1.77\; Kg = 5.299\; Kg$$

$$W_{HM} = M_{HM} x\; \mathrm{g} = 5.299 Kg\; x9.81\; {}^{m}/_{s^2} = 51.983\; N \ldots\ldots\ldots\ldots\ldots \text{(3.17)}$$

Where: - A_{HM} = 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

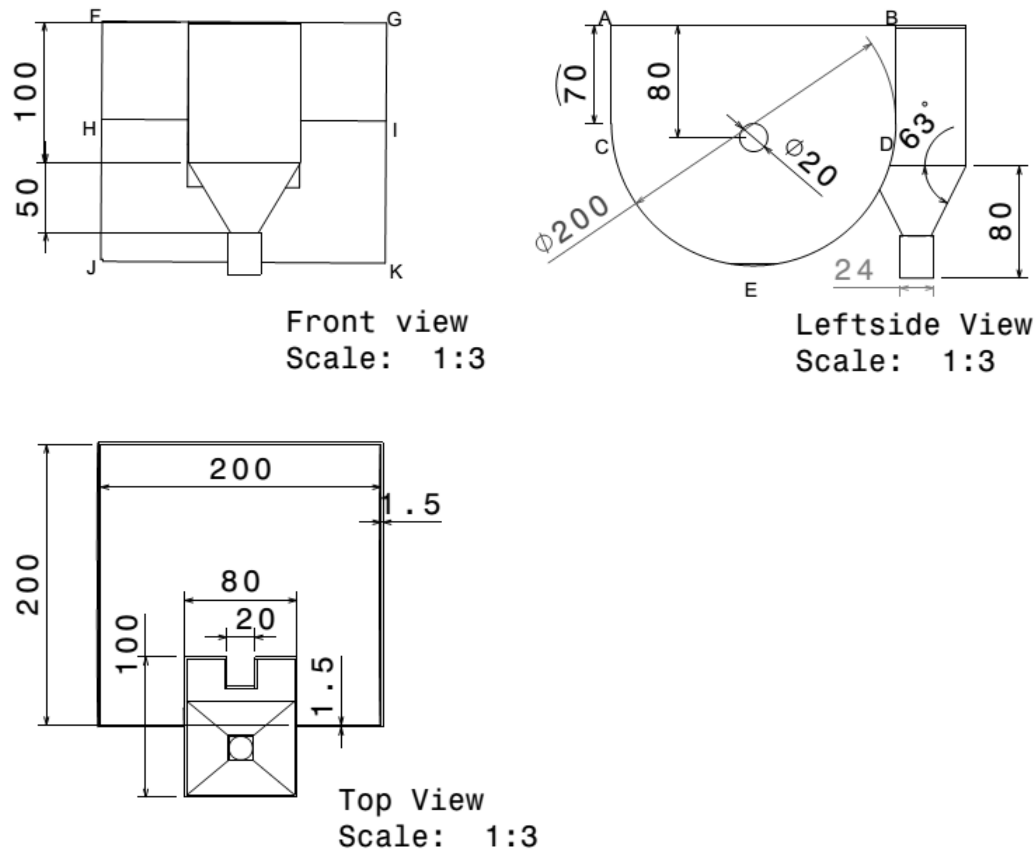

Fig. 3.8 Parts and dimensions of the hopper

Weight of the bracket in the hopper:

$$A_{BM} = 2x[(70x100) + (0.5x30x100) + (80x100) + (2x55.9x20) + (2x0.5x55.9x25) + (2x0.5x55.9x30)] - (20x72)$$

$$A_{BM} = 42{,}181mm^2 = 4.218x10^{-2}\,m^2$$

$$V_{BM} = A_{BM}xt_{BM}$$

$V_{BM} = 4.2x10^{-2}\, m^2 x2x10^{-3}\, m = 8.436x10^{-5} m^3$

$M_{BM} = V_{BM} x\rho\ _{BM}$

$M_{BM} = 8.436x10^{-5} m^3\ x7850\ {}^{Kg}/_{m^3}\ =\ 0.662\ Kg$

Since we have two brackets, i.e., one on each seed hopper

$M_{BM} = no.brackets\ xM_{BM} = 2x\ 0.662\ Kg = 1.324\ Kg$

$W_{BM} = M_{BM} x\ \mathrm{g} = 1.324\ Kg\ \ Kg\ x9.81\ {}^{m}/_{s^2} = 12.988\ N$

Where: - A_{BM} = Surface area of the bracket material

V_{BM} = Volume of the bracket material

t_{BM} = Thickness of the bracket material

M_{BM} = Mass of the bracket material

W_{BM} = Weight of bracket material

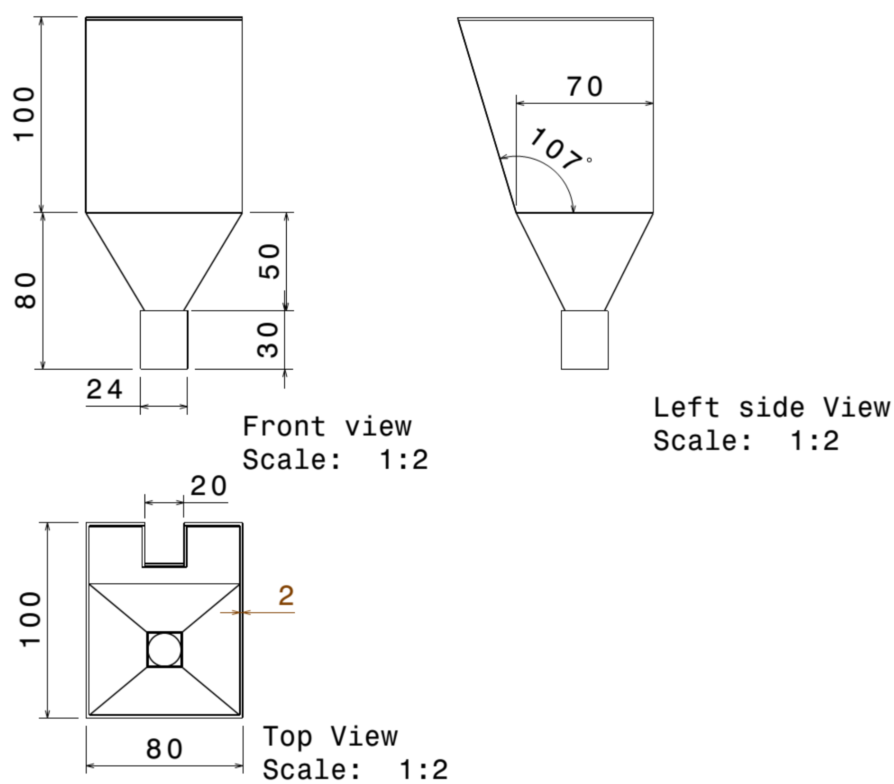

Fig. 3.9 Parts and dimensions of the bracket

3.3.11.2. Weight of the Planter Frame

Rectangular hollow pipe was used in the construction of the planter frame (Figure 3.3). The weight of frame was calculated as follows.

The cross sectional area of the hopper material can be calculated as:

$$A_{cross\ section} = A_{outer} - A_{inner} \quad (3.18)$$

$$= (20x20) - (16x16) = 144mm^2$$

The length of frame material is:

$$L_{FM} = (4x930) + (2x290) + (4x265) + (4x215) + (2x130) = 6{,}480\ mm$$

The volume of frame material is:

$$V_{FM} = A_{cross\ section} x\ L \quad (3.19)$$

$$= 144mm^2 x6{,}480\ mm = 933{,}120\ mm^3 = 0.000933\ m^3$$

Mass of frame material is:

$$M_{FM} = V_{FM} X \rho_{FM} = 0.000933\ m^3 x7850\ {}^{Kg}/_{m^3} = 7.32\ kg \quad (3.20)$$

Weight of frame material is:

$$W_{FM} = M_{FM} x\ g = 7.32\ kg x9.81\ {}^{m}/_{s^2} = 71.809N \quad (3.21)$$

Where: - $A_{cross\ section}$ = Cross sectional area of frame material

V_{FM} = Volume of frame material

L_{FM} = Length of frame material

M_{FM} = Mass of frame material

ρ_M = Density of frame material

W_{FM} = Weight of frame material

3.3.11.3. Weight of the Seed Metering Plate

The weight of the metering rollers, shown in Figure 3.5, used to meter the seed and fertilizer were estimated as follows:

$$V_{cm} = \left(6\,x\,\frac{\pi({D_c}^2 - {d_c}^2)}{4}\,x\,h\right) + 2x\left(\frac{\pi(\,{d_{small}}^2)}{2x4} + \frac{\pi({D_{large}}^2 - {d_{small}}^2)}{2x4}\right)\,x\,t\ +$$

$$(140\pi + (6x15))x15xt\ - 2x(\,20\pi) \quad \text{.......... (3.22)}$$

$$V_{cm} = \left(6\,x\,\frac{\pi(15^2 - 13^2)}{4}\,x\,15\right) + 2x\left(\frac{\pi(\,125^2)}{4} + \frac{\pi(140^2 - 125^2)}{2x4}\right)\,x\,1.5 + (132.5\pi + (6x15))x15x1.5\ - 2x(\,20\pi)$$

$$V_{cm} = 3{,}958.41 + 41{,}498.48 + 11{,}390.87 - 125.66 = 56{,}722.1\ mm^3$$

$$V_{cm} = 5.67x10^{-5}\,m^3$$

$$M_{cm} = V_{cm}x\rho_{\,cm} \quad \text{.......... (3.23)}$$

$$= 5.67x10^{-5}\,m^3x\ 7850\ {}^{Kg}/_{m^3}\ =\ 0.445kg$$

$$W_{cm} = 4xM_{cm}xg \quad \text{.......... (3.24)}$$

$$= 4x\ 0.445kgx9.81\ {}^{m}/_{s^2} = 17.462\ N$$

Where: - D_c= Outer diameter of cup

d_c = Inner diameter of cup

h = Height of cup

V_{cm} = Volume of metering plate

M_{cm} = Mass of metering plate

W_{cm} = Weight of metering plate

3.3.11.4. Weight of Furrow Opener

The weight of the furrow opener used, shown in Figure 3.6, was estimated as follows:

$V_{FOM} = 2x\left(\frac{\pi(D^2+d^2)}{4}\right)t + (A_{x-sec}xL_{FOM}) + 2x\left(\frac{\pi(D_h{}^2-d_h{}^2)}{4}\right)L_h + 2x(A_p x t_p)$ .... (3.25)

$$V_{FOM} = 2x\left(\frac{\pi(110^2+40^2)}{4}\right)x\,6 + (15x15x400) + 2\left(\frac{\pi(26^2-20^2)}{4}\right)x50 + 2x(90x50x3)$$

$$V_{FOM} = 129{,}119.46 + 90{,}000 + 21{,}676.99 + 27{,}000 = 267{,}796.45mm^3 = 0.000268m^3$$

$M_{FOM} = V_{FOM} x \rho_{FOM}$ .... (3.26)

$$= 0.000268m^3 \; x \; 7850 \,{}^{Kg}/_{m^3} = 2.104kg$$

$W_{FOM} = nxM_{FOM}xg$... (3.27)

$$= 2\;x\;2.104kg\;x\;9.81\,{}^{m}/_{s^2} = 41.281\,N$$

Where: - L_{FOM} = length of furrow opener materials

w_{FOM} = width of furrow opener materials

t_{FOM} = thickness of furrow opener materials

A_{FOM} = Surface area of furrow opener material

V_{FOM} = Volume of furrow opener material

M_{FOM} = Mass of furrow opener material

P_{FOM} = Density of furrow opener material

W_{FOM} = Weight of furrow opener material

3.3.11.5. Weight of Furrow Covering Device

The weight of the furrow covering devices was estimated as follows:

$A_{FCM} = L_{FCM}\;x\;w_{FCM}$ .... (3.28)

$A_{FCM} = \quad 19{,}513.8\, mm^2$

$V_{FCM} = A_{FCM}\ x\ t_{FCM}$ .... (3.29)

$V_{FCM} = 19{,}513.8\, mm^2 x 3mm = 58{,}541.4 mm^3 = 5.85x10^{-5} m^3$

$M_{FCM} = V_{FCM} x \rho_{\,FCM}$ .... (3.30)

$= \ 5.85x10^{-5} m^3 x \ \ 7850\, {}^{Kg}/_{m^3} \ = 0.459kg$

$W_{FCM} = nxM_{FOM}xg$

$= 2\ x\ 0.459kg\ x\ 9.81\, {}^{m}/_{s^2} = 9.005\ N$... (3.31)

Where: - L_{FCM} = length of furrow covering material

w_{FCM} = width of furrow covering material

t_{FCM} = thickness of furrow covering materials

A_{FCM} = Surface area of furrow covering material

V_{FCM} = Volume of furrow covering material

M_{FOM} = Mass of furrow covering material

P_{FCM} = Density of furrow covering material

W_{FOM} = Weight of furrow covering material

3.3.11.6. Weight of Seed Tube

The weight of the seed tubes/spouts was estimated as follows:

$V_{STM} = (A_{STM}\ x\ L_{STM}\,)$.. (3.32)

$$V_{STM} = \left(\frac{\pi(\,D^2 - d^2)}{4} x\ L_{STM} \right)$$

$$V_{STM} = \left(\frac{\pi(20^2 - 14^2)}{4} x\, 50 \right) = 8{,}011.06\, mm^3 = 8.011x10^{-6}m^3$$

$$M_{STM} = V_{STM} x \rho \quad \text{..........} (3.33)$$

$$= 8.011x10^{-6}m^3 x 7850\, {}^{Kg}/_{m^3} = 0.063kg$$

$$W_{STM} = nM_{STM} x g = 2x0.063kgx9.81\, {}^{m}/_{s^2} = 1.236\, N \quad \text{..........} (3.34)$$

Where: - L_{STM} = length of seed tube materials

w_{STM} = width of seed tube materials

t_{STM} = thickness of seed tube materials

A_{STM} = Surface area of seed tube material

V_{STM} = Volume of seed tube material

M_{STM} = Mass of seed tube material

ρ_{STM} = Density of seed tube material

W_{STM} = Weight of seed tube material

3.3.11.7. Weight of Grain and Fertilizer

The weight of the grain and fertilizer in the hoppers was estimated from the volume of the hopper determined earlier (section 3.3.2.) and bulk density of the seeds as follows:

$$M_{g+f} = 2x \left(V_h x\, \rho_{grain} \right) + \left(V_h x\, \rho_{fertiizer} \right) \quad \text{..........} (3.35)$$

$$M_{g+f} = 2x \left(0.0058\, m^3 x\, 720\, {}^{Kg}/_{m^3} \right) + \left(0.0058\, m^3 x 801\, {}^{Kg}/_{m^3} \right) = 12.998\, kg$$

$$W_g = M_{g+f} x\, g \quad \text{..........} (3.36)$$

$$= 12.998\, kg\ x 9.81\, {}^{m}/_{s^2} = 127.508N$$

Where: - M_G = mass of grain

V_h = volume of hopper

ρ_G = bulk density of seeds

W_G = weight of seeds in the hopper

3.3.11.8. Weight of the Metering Shaft

$$A_{sh} = \frac{\pi(D^2)}{4} \quad \text{......} \quad (3.37)$$

$$= \frac{\pi(20^2)}{4} = 314.159mm^2 = 3.142x10^{-4}m^2$$

$$V_{sh} = A_{sh}xL_{sh} \quad \text{......} \quad (3.38)$$

$$= 3.142x10^{-4}m^2x0.97m = 3.048x10^{-4}m^3$$

$$M_{sh} = V_{sh}x\rho_{sh} \text{......} \quad (3.39)$$

$$= 3.048x10^{-4}m^3x7850\,{}^{Kg}/_{m^3} = 2.393kg$$

$$W_{sh} = M_{sh}xg \quad \text{......} \quad (3.40)$$

$$= 2.393kg \ \ x\,9.81\,{}^{m}/_{s^2} = 23.475N$$

Where: - A_{sh} = Area of shaft

V_{sh} = Volume of shaft

ρ_{sh} = Density of shaft material

M_{sh} = Mass of shaft material

W_G = Weight of shaft material

3.3.11.9. Weight of Lid

The weight of the lid was estimated as follows:

$A_{lid} = L_{lid} x W_{lid}$ .... (3.41)

$= 2x\big((8x260) + (0.5x42x260)\big) + (50x920) + (8x920) + (260x920)$

$A_{lid} = 307{,}640mm^2$

$V_{lid} = A_{lid} x t_{lid}$ .... (3.42)

$= 307{,}640mm^2 x 1.5mm = 461{,}460mm^3 = 4.61x10^{-4}m^3$

$M_{lid} = V_{lid} x \rho_{lid}$ .... (3.43)

$= 4.61x10^{-4}m^3 x 7850\, {}^{Kg}/_{m^3} = 3.62\, kg$

$W_{lid} = M_{lid} x g$ .... (3.44)

$= 3.62\, kg x\, 9.81\, {}^{m}/_{s^2} = 35.512N$

Where: - A_{lid} = Area of lid

L_{lid} = Length of lid

V_{lid} =Volume of lid

W_{lid} = Width of lid

ρ_{sh} = Density of lid material

M_{sh} = Mass of lid material

W_G = weight of lid material

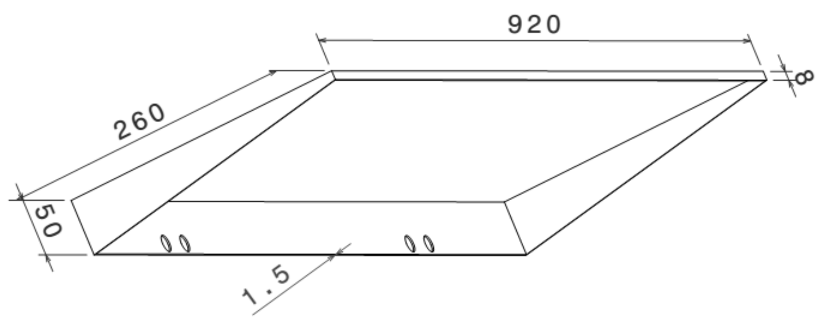

Fig. 3.10 Isometric view of the lid

3.3.11.10. Weight of Handle

$A_H = \left(\frac{\pi(D^2-d^2)}{4}\right)$ .... (3.45)

$= \frac{\pi(20^2 - 14^2)}{4} = 160.221mm^2 = 1.60x10^{-4}m^2$

$L_H = 2x(400 + 400 + 280) + 700 + 2x(180) + 450 = 3{,}670mm = 3.67m$

$V_H = (A_H \; x \; L_H)$ .... (3.46)

$V_H = 3.670mx1.602x10^{-4}m^2 = 5.88x10^{-4}m^3$

$M_H = V_H x \rho$ .... (3.47)

$= 5.879x10^{-4}m^3x7850 \, {}^{Kg}/_{m^3} = 4.62kg$

$W_H = M_H x g$ .... (3.48)

$= 4.615kgx9.81 \, {}^{m}/_{s^2} = 45.27 \, N$

Where: - A_H = Area of handle

L_H = Length of handle

V_H =Volume of handle

ρ_H = Density of handle

M_H = Mass of handle

W_H= weight of handle

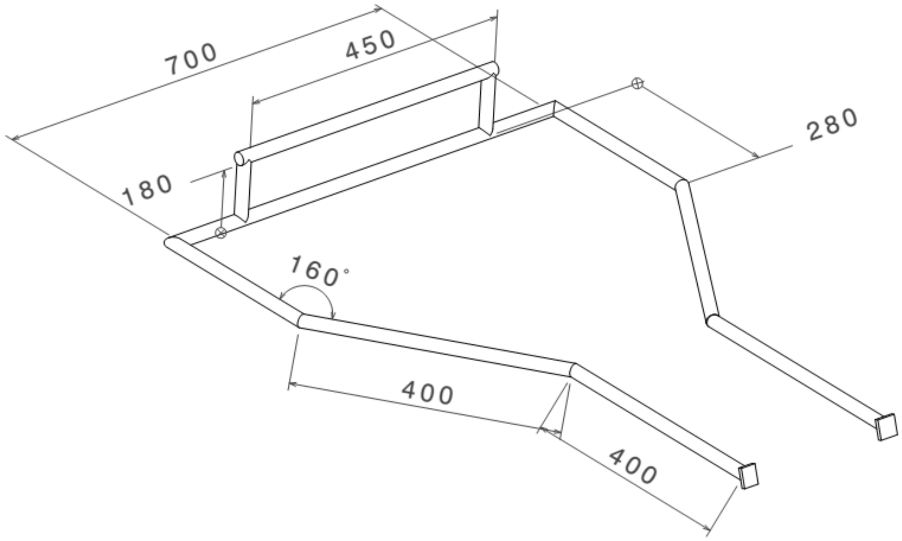

Fig. 3.11 Isometric view of the handle

3.3.11.11. Total weight of the prototype planter

The total weight of the prototype planter including the weights of seed and fertilizer hopper, bracket, frame, seed metering roller, metering shaft, furrow opener, furrow coverer, seed tube, seed and fertilizer, lid and handle was estimated to 437.532 N. Taking 2% margins for the weights of welding bolts, nuts, chains, etc. the total weight was found to be 446 N.

3.3.12. Estimation of Force, Torque and Power Required to Drive the Planter

3.3.12.1. Estimation of Force Required to Drive the Planter

A rolling resistance force (F), which is assumed to act horizontal at the wheel and ground interface or ground and wheel contact patch, was estimated using Eq. (3.49) (Reece, 2002).

$$F = (C_R + i) x N \quad \text{.......} \quad (3.49)$$

$$F = \left(\left(\frac{z}{d}\right)^{0.5} + i\right) x N$$

$F = \left(\left(\frac{2.5}{47.75}\right)^{0.5} + 0.05\right) * 223 = 62.17N$

Where: - C_R = coefficient of rolling resistance

d = wheel diameter, 477.5 mm

z = maximum wheel sinkage depth (on a soft surface z = 0.05d, let z ≈ 2.5cm)

N = weight of the planter on each wheel, (446/2) =223N

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

According to Kefyalew (2014), the resultant pull force performance of the donkey (475.39 N) is much higher than the calculated value. Therefore, the prototype planter can easily be pulled by a donkey.

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

$T = F(\frac{d}{2})$.. (3.50)

$T = (62.17) * (\frac{0.4775}{2})$

$T = 14.84Nm$

3.3.12.3. Power Requirement of the Planter…………… (Sharma and Mukesh, 2010)

The wheel covers 1.50 m in one revolution and taking a 0.5m/s forward speed of donkey drawn planter (Kefyalew, 2014), we will have 20 RPM.

$P = T * Nw$……………………………………...…… (3.51)

$= (14.84) * (20x2\pi/60)$ …………where: - N_w= wheel revolution, 20 RPM

$= 31.08W$

$= 0.03\ KW$

3.3.13. Wheel design

Two ground engaging wheels, with external diameters of 47.75 cm, were designed as an integral part of the seed metering mechanism. They are connected to the seed metering device through a shaft where one of them produces the necessary force to drive the seed and fertilizer plates through chain-sprocket drive. The rim of wheel was made from mild steel flat iron 6 mm thick and 80 mm wide. Each wheel had eight spokes made from mild steel rods with diameter of 8 mm and length of 257 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. 3.12).

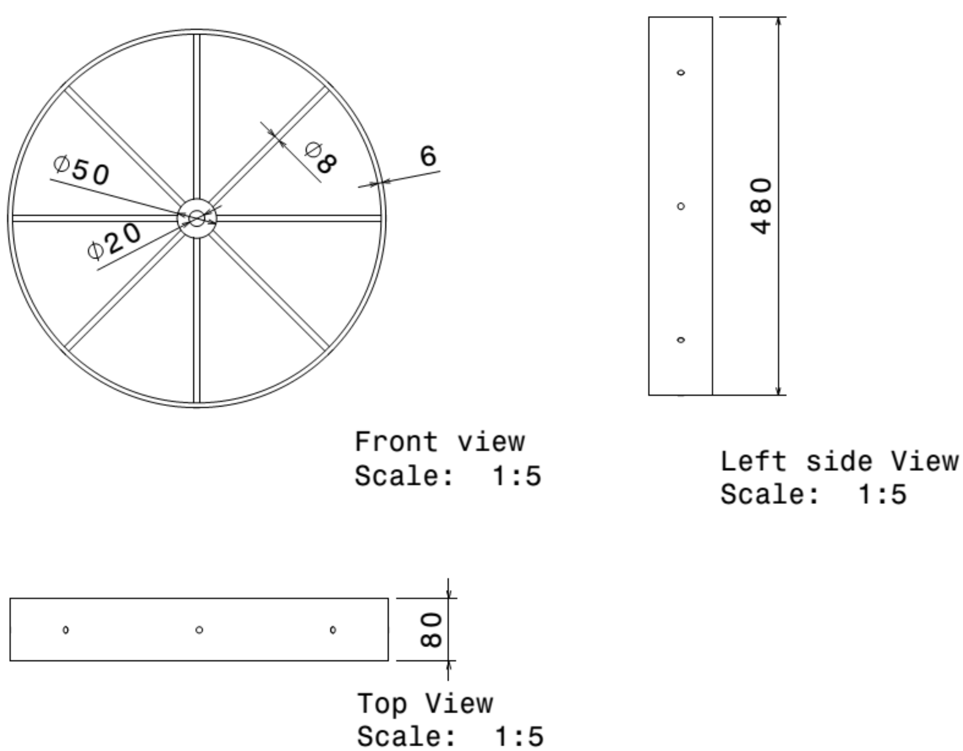

Fig. 3.12 Ground wheel

3.3.13.1. Wheel strength

The wheel of the planter was made from mild steel sheet metal whose maximum shear strength, τ_{max}, is 80 MPa. Reinforcing bars were used to strengthen the wheels. For the simplicity of the analysis, it was assumed that the stress occur on the wheel was pure torsion. Therefore, 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).

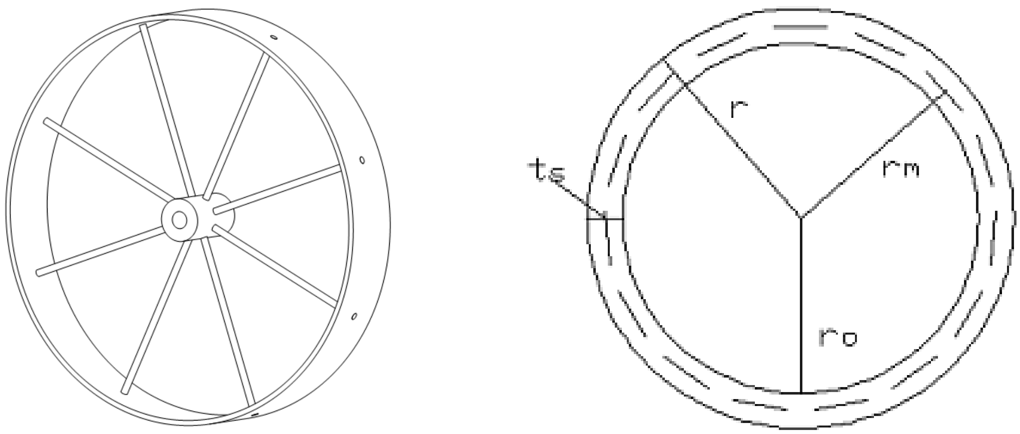

Fig. 3.13 Three dimensional and cross sectional view of the wheel

$$\tau = \frac{T}{2A_m t_s} \quad (3.52)$$

$$\tau = \frac{T}{2(\pi r_m{}^2)t_s}$$

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

Where: - T= the torque produced by the wheel, 14.84 Nm

A_m=the area of the wheel calculated based on the median diameter of the wheel (fig.3.13)

r= the outer radius of the wheel, 0.239m

r_o= the inner radius of the wheel, 0.233m

r_m= the median radius of the wheel

t_s= the thickness of the wall/wheel=0.006m

Therefore, the shear stress on the wheel is,

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

$$\tau = \frac{14.84}{2(\pi[0.239 - 0.003]^2)x0.006}$$

$$\tau = 7{,}067.71\ Pa$$

$$\tau = 7.07\ KPa\ \lll\ \tau max$$

Comparing the result, $\tau_{ac} \lll \tau_{max}$, indicated the wheel was safe.

The angle of twist can be estimated using the equation below (Richard *et al*, 2011).

$$\theta = \theta_1 L \ldots\ldots (3.53)$$

$$\theta = \left(\frac{TL_m}{4GA_m{}^2 t_s}\right) xL$$

$$\theta = \left(\frac{14.84x2\pi\ (0.239 - 0.003)}{4x80x0.0437^2x0.006x10^9}\right) x0.08$$

$$\theta = 4.80\ x\ 10^{-7} rad$$

$$\theta = 2.752x10^{-5} degree\ (negligible)$$

Where L= length or width of the wheel, 0.08m

T= torque produced by the wheel, 14.84Nm

L_m=the length of the median line of the wheel

θ_1=the angle of twist

G= modulus of rigidity, 80GPa for stainless steel

The angle of twist produced by the wheel is negligible since the torque is small.

3.3.13.2. Estimation of wheel width

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 (Hertz, 1881). The following equations are used to calculate the half width and pressure:

$$b = \ [(2F/\pi L)\ [(1-v_1{}^2)/E_1\ +\ (1-v_2{}^2)/E_2]/\ (d_1{}^{-1} + d_2{}^{-2})\}^{0.5} \ \ldots\ldots\ldots\ldots\ldots\ (3.54)$$

$$P_{max} =\ 2F/\pi bL \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.55)$$

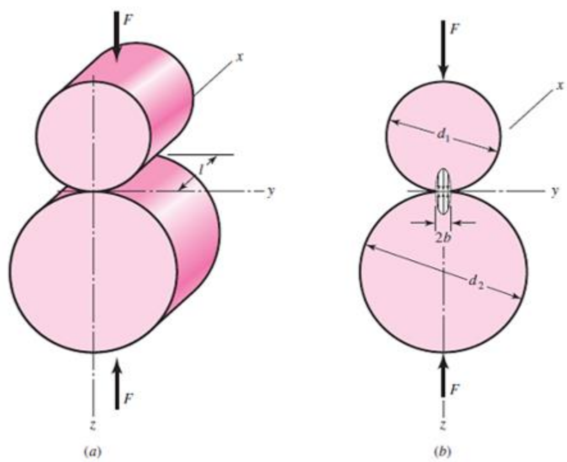

Fig. 3.14 Contact stress between two cylinders

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: - v1= 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, 0.48m

d_2= diameter of the contacting surface, ∞

F= the force exerted by the wheel, 223N

L= contact length/width of the wheel with the ground, 0.08m

P_{min}= the minimum penetration resistance/pressure of the ground (0-10 cm) at optimum moisture content, 500 KPa.

The width of wheel specified in the design was 8 cm 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 (P_{max}) developed on the contact patch (wheel and ground) was compared with the minimum con-index (P_{min}) measured at 0-10cm depth using cone-penetrometer. If $P_{max}<P_{min}$, it is assumed that the width of the wheel is safe. However, if $P_{max} > P_{min}$, the width of the wheel has to be increased to some level to avoid wheel sinkage in operation.

Solving for b,

$$b = \{(2F/\pi L)\ [(1-v_1{}^2)/E_1 + (1-v_2{}^2)/E_2]/\ (d_1{}^{-1} + d_2{}^{-2})\}^{0.5}$$

$$= \{(2x223/0.08\pi)\ [(1-0.3^2)/(200x10^9) + (1-0.4^2)/(50x10^6)]/\ (1/0.48 + 1/\infty)\}^{0.5}$$

$$= 3.79x10^{-3}m$$

Solving for P_{max},

$$P_{max} = 2F/\pi bL$$

$$= 2x223/\pi(0.08x3.79x10^{-3})$$

$$= 468.23\ KPa \ < 500\ KPa\ \ (safe)$$

The selected width of the wheels is sufficient and the wheels will rotate on the surface of the ground without sinking into the soil.

3.3.14. Chain Design

Chains are used for power transmission between parallel shafts. They can be employed for high loads and where precise speed ratios must be sustained. While precise location and alignment tolerances are not required, as with gear drives, the best performance can be expected when input and output sprockets lie in the same vertical plane.

Power transmission, in the prototype planter from the wheel shaft to metering shaft, was through chain drive. When pushing the planter the sprocket on the wheel shaft rotates and transfers the power to seed metering shaft sprocket with the help of chain, in such a way seed metering wheel rotate, seed was singulated into the cell and dropped into the opened furrow with the help of seed discharge tube that deposits the seed in the soil. The number of teeth in small gear sprocket and large gear sprocket is in a one to one ratio. The velocity of the chain, its strength and length were determined as follows:

3.3.14.1. Chain Velocity

Average chain velocity (Crutz *et al.*, 2012)

$$Vav = \frac{PxNxRPM}{376} \quad \text{.......... (3.56)}$$

$$Vav = \frac{0.25x15x20}{376} = \frac{1.905m}{min} = 0.20\, m/s$$

Where: - N= no. of teeth on sprocket, 15

RPM= revolution of the driving sprocket, 20 rev/min

P= commercially available chain pitch, 0.25 inch

3.3.14.2. Chain Force .... (Sharma and Mukesh, 2010)

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

$$F_T = F + F_c + F_f \quad \text{.......... (3.57)}$$

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

w= weight per meter of the chain, 6.76N/m

g= gravitational attraction, m/s2

C_c= nominal center to center distance between the sprockets, 0.15m

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

P= power at the planter wheel/ power to be transmitted/, 0.042Hp

k_f= friction factor (4 for horizontal drive, 2 for inclined drive and 1 for vertical drive)

$$F = \frac{P}{V_{av}} \quad \text{.......... (3.58)}$$

$$= \frac{31.08}{0.20}$$

$$= 155.40\ N$$

$$F_c = \frac{wxV_{av}{}^2}{g} \quad \text{.......... (3.59)}$$

$$= \frac{6.6x0.2^2}{9.81}$$

$$= 0.027\ N$$

$$F_f = w * K_f * C_c \quad \text{.......... (3.60)}$$

$$= 6.6 * 1 * 0.15$$

$$= 0.99\ N$$

$F_T = F + F_c + F_f$

$F_T = 155.40\ N + 0.027\ \ N + \ 0.99\ N$

$= 156.42\ N$

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

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

$S_f = \frac{T_{sm}}{F_T}$ .... (3.61)

$= \frac{3470}{156.42}$

$= 22.18$

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

3.3.14.3 Chain length……….........… (Sharma and Mukesh , 2010 and Ajit K. *et al*., 2012)

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

$L_c = \ P * \ L_p$ .... (3.62)

$Lp\ = 2C_p\ + \ (N_1 + N_2)/2 + \ [\frac{N_2 - N_1}{2\pi}]^2\ /C_p$ .... (3.63)

$C_p\ = \frac{C_c}{P}$ .... (3.64)

Where: - Lc= chain length, m

L_P=chain length, in pitches

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

C_c=approximate center to center distance between the sprockets, 150 mm

P= chain pitch, 6.35mm

N_1=number of teeth of the driven sprocket, 15

N_2=number of teeth of the driving sprocket, 15

Solving for C_p

$$C_p = \frac{C_c}{P}$$

$$C_p = \frac{150}{6.35}$$

$$C_p = 23.62$$

Solving for L_p

$$Lp = 2C_p + (N_1 + N_2)/2 + [\frac{N_2 - N_1}{2\pi}]^2 /C_p$$

$$= 2x23.62 + (15 + 15)/2 + [\frac{15 - 15}{2\pi}]^2 /23.622$$

$$= 62.24$$

$$= 62 \, pitches$$

Solving for Lc

$$L_c = P * L_p$$

$$= 6.35 * 62$$

$$= 393.70 \, mm$$

$$= 0.39 \, m$$

Now, since the chain length in pitches is changed from 62.244 to 62 pitches, the center to center distance of the sprockets has to be corrected.

$C = [e + (e^2 - 8m)^{\frac{1}{2}}]\frac{P}{4}$ ………….. (3.65)

(Sharma and Mukesh, 2010)

Where: - $e = L_p - \frac{(N_1+N_2)}{2} = 130$ .... (3.66)

$$e = 62 - \frac{(15 + 15)}{2} = 47$$

$m = [\frac{(N_2 - N_1)}{2\pi}]^2 = 0$ .... (3.67)

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

$$C = [47 + (47^2 - 8x0)^{\frac{1}{2}}]\frac{6.35}{4}$$

$$= 149.26\ mm$$

3.3.15. Shaft Design

A shaft is a rotating machine element which is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and the resultant torque (or twisting moment) set up within the shaft permits the power to be transferred to various machines linked up to the shaft. In order to transfer the power from one shaft to another, the various members such as pulleys, gears etc., are mounted on it. These members along with the forces exerted upon them causes the shaft to bending. In other words, we may say that a shaft is used for the transmission of torque and bending moment. The various members are mounted on the shaft by means of keys or splines.

The design of the wheel shaft was based on ductile material (mild steel) 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 ASME code equation (Eq.3.68), (ASME, 1995) given as follows:

$$d^3 = \frac{16}{\pi S_s}\sqrt{[(K_b M_b)^2 + (K_t M_t)^2} \quad \text{.......... (3.68)}$$

Where: - d = diameter of the shaft; mm

M_t= torsional moment; Nm

M_b= bending moment; Nm

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

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

S_s= allowable stress; MN/m^2

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 (S_s) must be 55 MN/m^2, and for the shaft with key way the allowable stress (S_s) should not exceed 40 MN/m^2.

Torsional moment (M_t) on the shaft was calculated using Eq. (3.61 and 3.62) (Ryder, 1989).

$$M_t = \frac{Px60}{2\pi N} \quad \text{.......... (3.69)}$$

$$P = FxV \quad \text{.......... (3.70)}$$

$$P = 62.17Nx0.5\, m/s$$

$$P = 31.08\, W$$

$$M_t = \frac{31.08x60}{2\pi x20} = 14.84\, Nm$$

Where: - P = power required to drive the machine;

N = speed of the shaft

V = forward speed

F = force required to drive the machine

Figure 3.15 shows the load distribution on the shaft. The maximum bending moment on the shaft was determined from the following expressions:

$$M_b = \sqrt{{M_v}^2 + {M_h}^2} \qquad (3.71)$$

The vertical, horizontal, driving and chain forces acting on the wheel shaft are shown in figure 3.15 below.

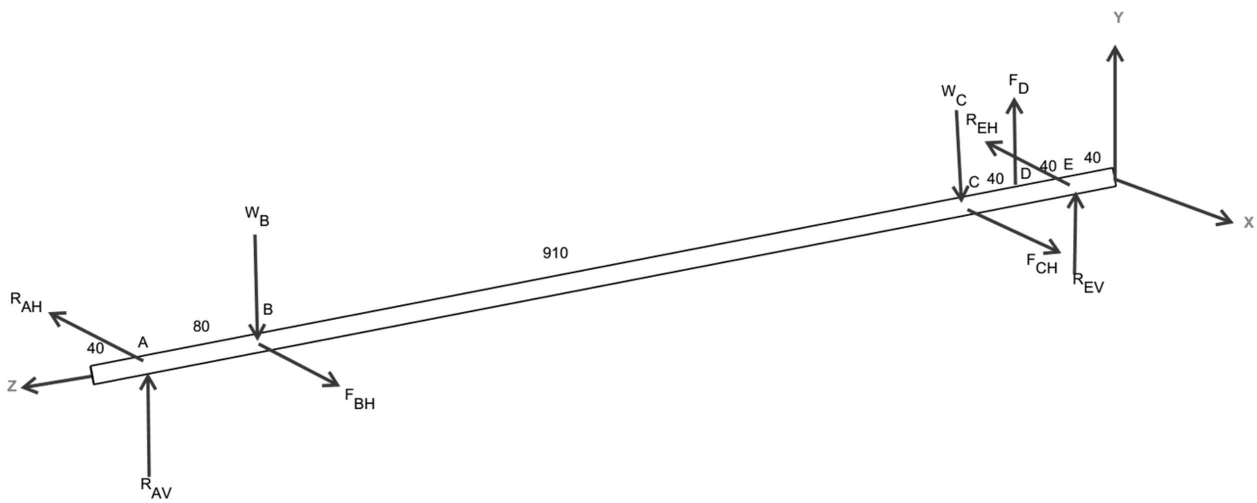

Fig. 3.15 Three dimensional view of the forces acting on the wheel shaft

Where: - R_{AV} = Vertical reaction at wheel A

R_{EV} = Vertical reactions at wheel E

W_B = Half of the total weight acting at bearing B (223 N)

W_C = Half of the total weight acting at bearing C (223 N)

R_{AH} = Horizontal reaction at wheel A

R_{EH} = Horizontal reaction at wheel E

F_{BH} = Pulling force of the planter at bearing B

F_{CH} = Pulling force of the planter at bearing C

F_D = Vertical chain force

3.3.15.1. Determination of vertical forces acting on the metering shaft

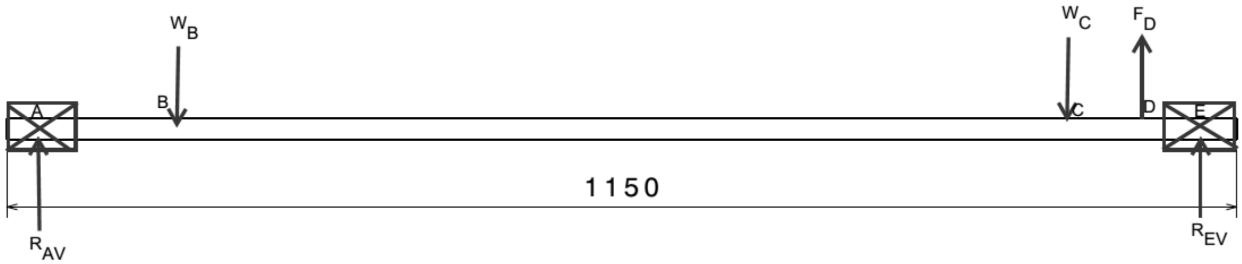

Fig. 3.16 Vertical forces acting on the wheel shaft

The reaction forces R_{AV} and R_{EV} were determined as follows:

$$\sum M_A = 0$$

$$(R_{EV} x 1070) + (F_D x 1030) - (W_C x 990) - (W_B x 80) = 0$$

$$(R_{EV} x 1070) + (156.42\ x 1030) - (223 x 990) - (223 x 80) = 0$$

$$(R_{EV} x 1070) = 77{,}497.4$$

$$R_{EV} = 72.43\ N$$

$$\sum F_Y = 0$$

$$R_{AV} + R_{EV} - W_B - W_C + F_D = 0$$

$$R_{AV} = 223 + 223 - 156.42 - 72.43$$

$$R_{AV} = 217.15\ N$$

The shear and bending moment diagrams were sketched in figure 3.17 below.

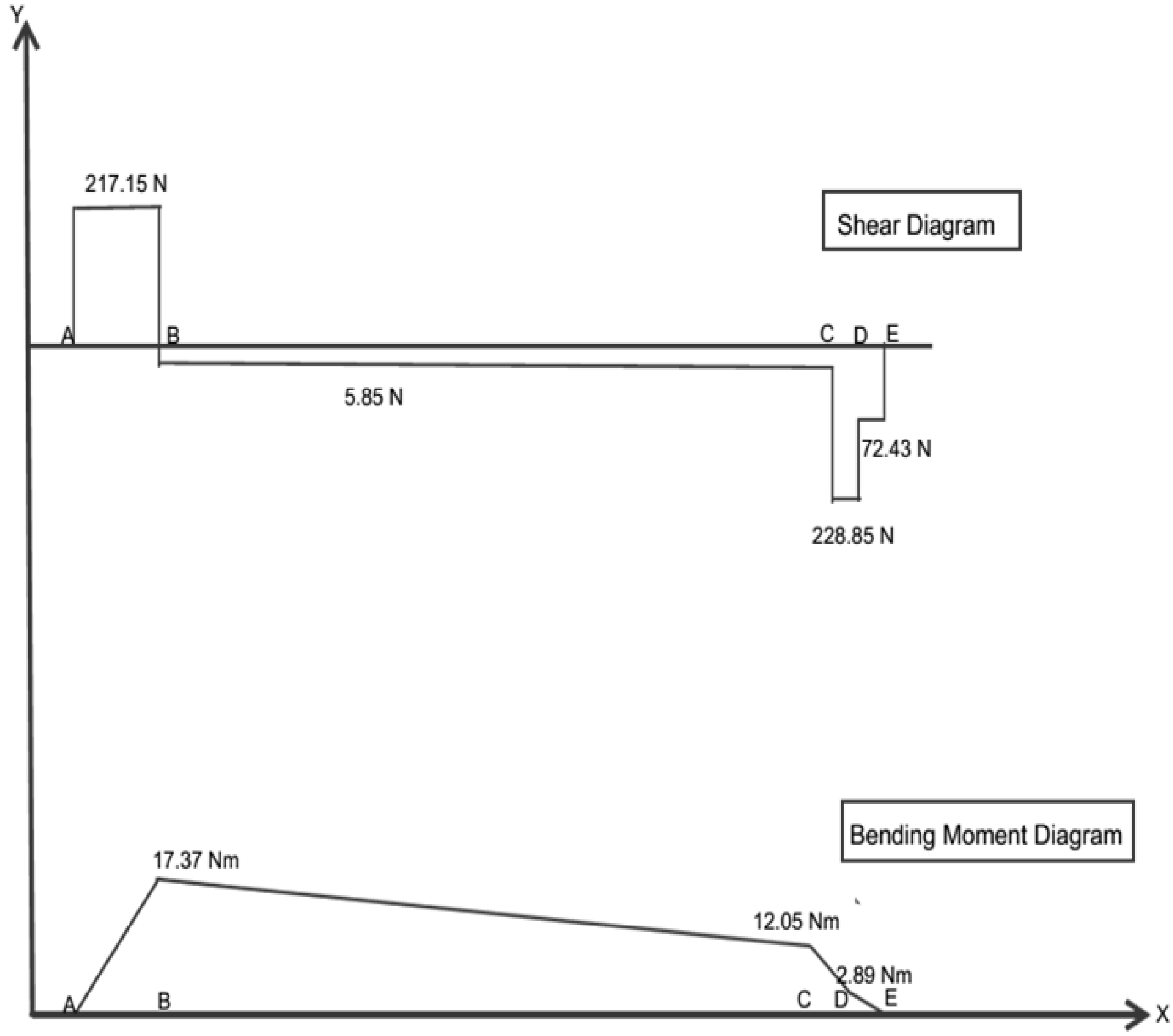

Fig. 3.17 Vertical forces shear and bending moment diagrams

The maximum vertical bending moment on the shaft was 17.37 Nm at 80 mm from A.

3.3.15.2. Determination of Horizontal forces acting on the metering shaft

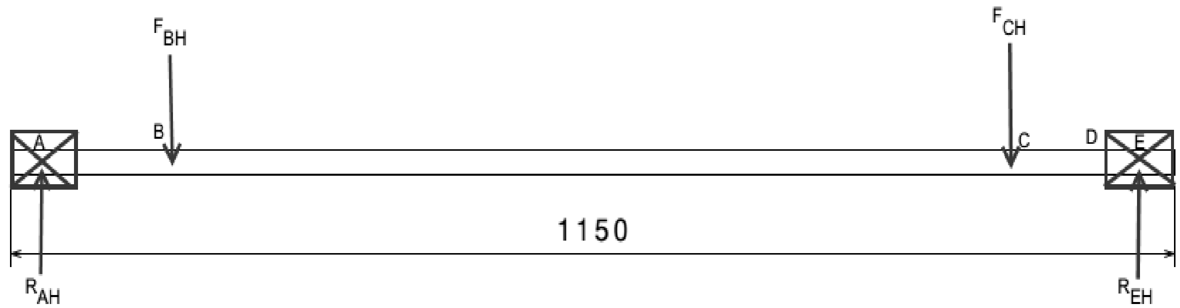

Fig. 3.18 Horizontal forces acting on the wheel shaft

The forward driving force is 62.17 N and applied horizontally at point B and C.

$$F_{BH} + F_{CH} = 62.17N$$

$$F_{BH} = F_{CH} = \frac{62.17}{2} = 31.09\ N$$

$$\sum M_A = 0$$

$$(R_{EH} x 1070) - (31.09 x 990) - (31.09 x 80) = 0$$

$$(R_{EH} x 1070) = 33{,}266.3$$

$$R_{EH} = 31.09\ N$$

$$\sum F_Y = 0$$

$$R_{EH} + R_{AH} = 62.17N$$

$$R_{AH} = 62.17N - R_{EH}$$

$$= 62.17N - 31.09\ N$$

$$= 31.09\ N$$

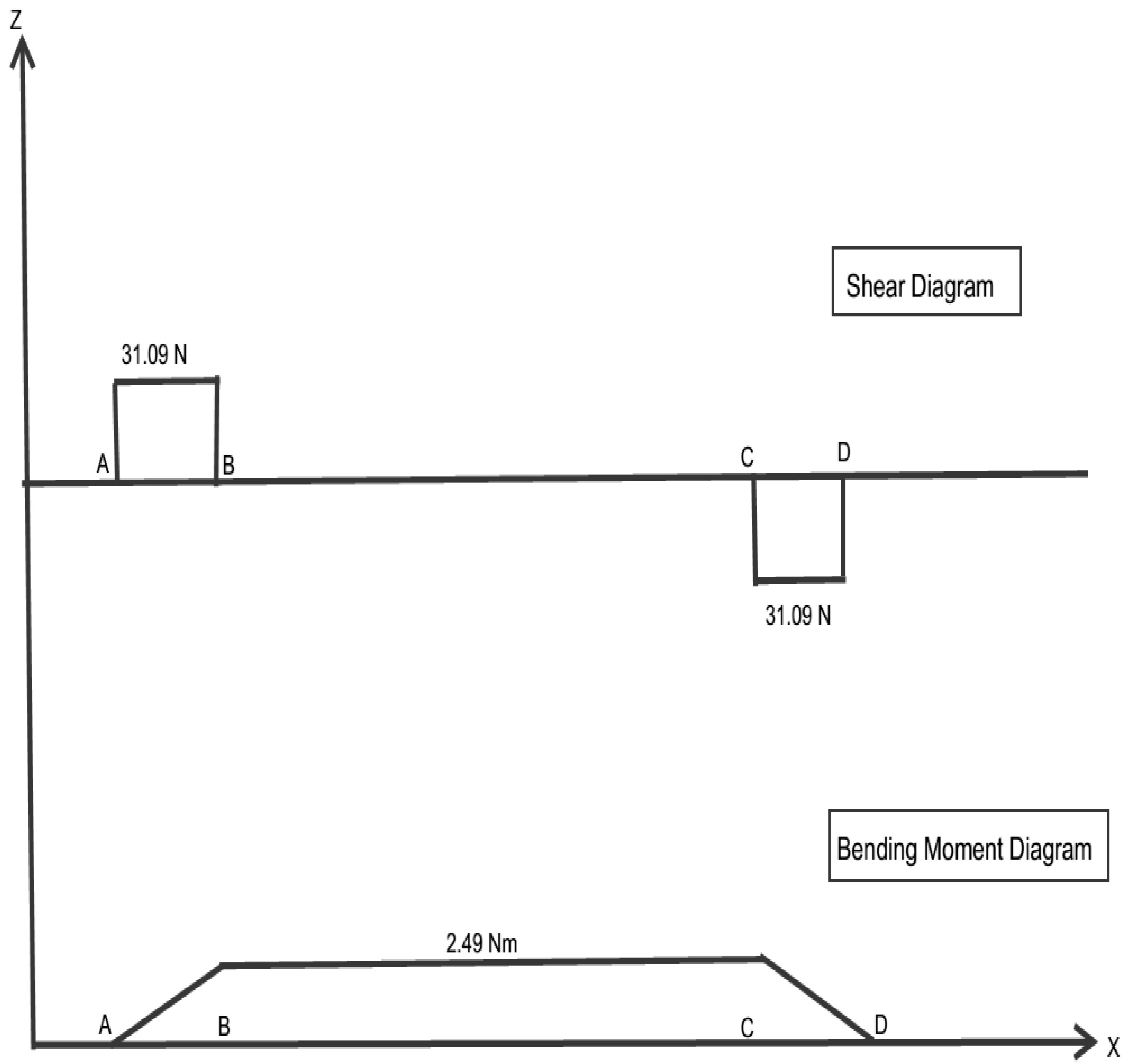

Fig. 3.19 Horizontal forces shear and bending moment diagrams

The maximum horizontal bending moment on the shaft was 2.49 Nm at 80 mm from A.

The total resultant components of horizontal and vertical bending moments on the shaft can be obtained as follows:

$$M_b = \sqrt{{M_v}^2 + {M_h}^2}$$

$$= \sqrt{17.37^2 + 2.49^2}$$

$$= 17.55\ Nm$$

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

Where: - M_t = 14.84 Nm

M_b = 17.37 Nm

K_b = 2

K_t = 1.5

S_s = 55 MN/m^2

$$= \frac{16}{55x10^6 x\pi}\sqrt{[(2x17.55)^2 + (1.5x14.84)^2}$$

$$= 0.00000385\ m$$

$$d = 15.67\ mm$$

Therefore, a **20 mm** diameter standard sized shaft has been used for the planter.

3.3.16. Performance Test and Evaluation

To check whether the machine was functionally acceptable or not, a preliminary test run was undertaken. The prototype planter had good stability in terms of operation and performed the required job acceptably.

Two tests were performed; laboratory evaluation and field test. In laboratory, investigation was made to calibrate the machine in terms of seed rate, seed damage, and seed spacing. Some physical properties of the seed were also measured. In field test, the planter was tested on a well prepared soil to determine the field performance and field capacity of the planter.

3.3.16.1. Evaluation of percent seed damage

The two seed hoppers of the planter were loaded with 2.5 kg of seeds and the planter was jacked up to a platform to allow free rotation of the drive wheels. A mark was made on the wheels to indicate the reference points to count the number of revolutions when turned and polythene bags were placed on the seed tubes to collect the seeds discharged. The wheels are rotated for 20 times with a speed of 0.5 m/s as would be obtained on the field when drawn by a donkey. A stop watch was used to measure time taken to complete the revolutions. The seeds collected in the polyethylene bags at the end of the 20th revolution of the wheel were weighed on the balance and examined for any external damage or visible crack to establish the performance of the metering rollers. To assess the level of internal damage by the metering mechanism, randomly picked seed samples were tested for germination at AIRIC laboratory. The following equation was used to determine the Percentage of external seed damage.

$$M_d = \frac{S_{nds}}{S_{ns}} * 100 \quad (3.72)$$

Where: - M_d = percentage of damaged seed

S_{nds} = total number of externally damaged seeds

S_{ns} = total number of seeds

3.3.16.2. Evaluation of Seed spacing/distribution

The planter was designed to drop two seeds per hill keeping the recommended 25cm spacing between two consecutive hills. It was evaluated both at laboratory and field using maize seeds at forward speeds of 1, 3 and 5 km/h while the hopper was loaded to its one fourth, one half, three fourth and full capacity. To assess uniformity of seed placement, the planter was pulled at predetermined forward speed on manually dug, leveled, fine sand applied, gently packed and watered soil surface which avoids seed bouncing. At the end of each test run, measurement of successive seed spacing was made with a measuring tape, seeds handpicked from the soil surface and preparation for the subsequent tests made through re-leveling the soil surface and watered the same to avoid seed bouncing or rolling from point of its landing. Well trained donkey and a guide man was used to pull the planter at desired speeds. Each test run was replicated three times over a distance of 10 m. Measurements made were used to calculate the mean seed spacing, seed miss index, seed multiple index, quality of feed index and precision in spacing. 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, X_{ref}, 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 X_{ref}, 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):-

Miss index (MISI)

Miss index is an indicator of how often a seed skips the desired spacing. It is the percentage of spacing greater than 1.5 times the theoretical spacing. Smaller values of M indicate better performance. It was calculated as follows:

$$MISI(\%) = \frac{n_{III}+n_{IV}+ n_V}{N} * 100 \quad \text{...} (3.73)$$

Where: - MISI = miss index

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

N = total number of spacings

Multiples index (MULI)

Multiple index is an indicator of more than one seed dropped within a desired spacing. It was estimated by measuring the distance between consecutive seeds, the spacings less than or equal to half of the theoretical (nominal) spacing and calculated as follows:

$$MULI\ (\%) = \frac{n_{I}}{N} * 100 \quad \text{...} (3.74)$$

Where: - MULI = multiple index

n_I = the number of spacings in region I and

N = total number of spacings

Quality of feed index (QTFI)

Quality of feed index is an indicator of uniformity of seed distribution in the row. It was estimated using the data obtained by measuring the consecutive distance between seeds in the row with spacings more than half but not more than 1.5 times the theoretical spacing and calculated using the equation given below:

$$QTFI\ (\%) = \frac{n_{II}}{N} * 100 \qquad \text{......} \ (3.75)$$

Where: - QTFI = quality of feed index

n_{II} = the number of spacing in division II and

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 *et al.*, 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:

$$PREC(\%) = \frac{S_{II}}{X_{ref}} * 100 \qquad \text{......} \ (3.76)$$

Where: - PREC = precision index

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

X_{ref} = the theoretical spacing.

3.3.16.3. Determination of field performance and field capacity

The field test was conducted on a rectangular fallowed farmland of 180 m^2 area having a sandy-loam soil texture. The field was prepared using local *ard* plough and the depth of planting was measured along the row at a distance of 18 m at three randomly selected locations/points. To ease the measuring activity, covering mechanism was not used

Field capacity and efficiency were determined in accordance to the recommendation made by Kepner (1978) and using relevant parameters that included effective operation time, turning time and time losses due to obstructions on the field. A plot of 18 m by 10 m requiring, on average, about fourteen passes with inter-row spacing of 0.7 m was used to assess field capacity and field efficiency. From the data gathered working speed (km/h), effective field capacity (ha/h) and field efficiency (%) were estimated using the expressions below:

$$V = \frac{D}{t_a} \quad \text{......} \quad (3.77)$$

Where: - V = Working speed,

D = distance of run (m)

t_a = average time of each pass (second)

$$e = 100 * \frac{T_e}{T_t} \quad \text{......} \quad (3.78)$$

Where: - e = field efficiency (%).

T_e = effective operating time (sec.)

T_t = total time = (effective operating time + time lost for turning)

$$C_e = \frac{W_e * S_{mf} * e}{10} \quad \text{.......} \quad (3.79)$$

Where: - C_e = effective field capacity (ha/hr)

W_e = implement effective width/inter row spacing (m)

S_{mf} = mean forward speed (km/h)

e = field efficiency (decimal value)

3.3.16.4. Experimental design

The experimental design used was a split-plot design. The split-plot design is specifically suited for a two-factor experiment that has more treatments than can be accommodated by a complete block design. In a split-plot design, one of the factors is assigned to the main plot. The assigned factor is called the main-plot factor. Thus, the four levels of hopper filling were assigned to main plot. The main plot was divided into subplots to which the second factor, called the subplot factor, was assigned. Thus, each main plot became a block for the subplot treatments (i.e., the levels of the subplot factor) (Gomez and Gomez, 1984). The three levels of forward speed of planter were assigned to sub plot. The experiment design was laid as 4x3 with three replications and had a total of 36 test runs (4x3x3=36).

3.3.16.5. Statistical Analysis

All the data collected during the laboratory and field performance evaluations were analyzed using Statistix 8 software, 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 use.

The data were subjected to analysis of variances following a procedure appropriate for the design of the experiment (Gomez and Gomez, 1984).

4. RESULTS AND DISCUSSION

The following are the details of the results obtained from performance evaluation of the prototype planter.

4.1. Physical Properties of the Seeds

Melkassa-138 maize crop variety was used in the study. Table 4.1 gives the mean values and the standard deviations of length, width, thickness, volume, geometric diameter, sphericity and thousands seed weight.

Table 4.1. Physical properties of maize seeds.

Physical properties	Samples size	Maize	Unit
Length	100	10.30±1.29	mm
Width	100	8.55±0.47	mm
Thickness	100	4.50±0.63	mm
Volume	100	206.39±37.26	mm^3
Geometric diameter	100	7.29±0.46	mm
Sphericity	100	71.56±7.10	%
Thousands seed weight	1,000	271±4.11	gm

The result obtained in Table 4.1 showed that maize seed had more or less spherical shape (sphericity = 71.56±7.10%). Hence, metering devices with circular shaped cups were used to accommodate it.

4.2. Performance Evaluation of the Prototype

4.2.1. Seed damage test

Randomly selected 50 samples that had passed through the metering plate were examined and the numbers of mechanically damaged, i.e. bruised, skin removed or crushed seeds were counted. The mean percent seed damage was found to be 1.01± 0.37%.

Seed damage increased with increasing metering roller speed and this was attributed to shearing and jumping of seeds against the wall of the hopper at high speeds and the magnitude of damage was depended on the strength of the seeds (Norris, 1982). The observed seed damage was due to low seed quality and high metering roller speed or defects caused by poor workmanships.

Germination test was conducted at AIRIC laboratory using metered seeds placed in Petri dishes. The result revealed that mean percentage germination was 94.58±0.21. Melkassa 138 maize seed variety had a mean percent germination rate of 95%. The difference can be related to the metering rollers quality, the variability of the seeds and the friction between the metering device and seeds. The reduction in percent germination was 0.42%, indicating that the mechanical damages caused by the metering devices on the respective seeds were within acceptable level, less than one percent.

4.2.2. Seed spacing analysis

4.2.2.1. The seed miss index

The analysis of variance (ANOVA) revealed that the planter forward speed and the interaction of planter forward speed with hopper loading level had significant effect ($p < 0.05$) on seed miss index (see Appendix A1).

Table 4.2 show the effect of speed of operation, level of seed filling in the hopper and the combined effect of speed and level of seed fill on mean percent of seed miss index. Figure 4.1 shows the relation between planter linear speed and mean percent of seed miss index.

Table 4.2. Effects of planter operating speed and hopper filling level on miss index (MISI)

Parameter	Source of variation				
	Speed level	Seed type			
		Maize			
MISI (%)	V_1	3.861			
	V_3	4.852			
	V_5	6.130			
	Hopper filling level				
	H_{25}	5.284			
	H_{50}	5.052			
	H_{75}	4.828			
	H_{100}	4.623			
	Interaction(V *H)				
	Speed level	H_{25}	H_{50}	H_{75}	H_{100}
	V_1	4.440	3.553	3.803	3.647
	V_3	5.170	4.943	4.760	4.533
	V_5	6.243	6.660	5.920	5.697

Operational speed had significant effect on percent of miss index at $p < 0.05$. Increasing speed of operation from 1 km/hr to 5 km/hr had increased the percent miss index.

In general, increase in operational speed tended to increase percent miss index when planting using the prototype planter. The highest percent seed miss index of 6.130 were recorded at the planter forward speed of 5 km/hr, whereas the lowest percent seed miss index of 3.861 were obtained at the planter forward speed of 1 km/hr. This clearly indicated that higher forward speed result in percent miss index which exceeds the acceptable level of percent miss.

From Table 4.2 and Appendix A1 it can be seen that the level of seed in the hopper, i.e. level of filling, also had significant effect on percent miss index. The combined effect of operational speed and hopper filling level had significant effect on percent miss index. However, the effect was dominantly due to variation in speeds than hopper level of filling.

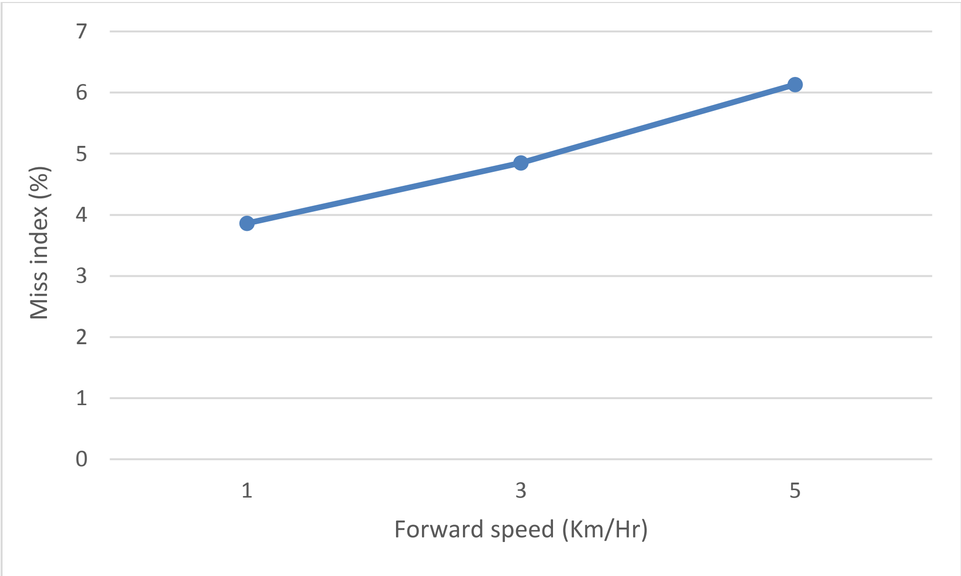

Fig. 4.1 Effects of planter forward speeds on seeds miss index

4.2.2.2. The seed multiple index

The analysis of variance (ANOVA) revealed that planter forward speed had significant effect ($p < 0.05$) on seed multiple index whereas, hopper loading level, and the interaction of planter forward speed and hopper loading level had no significant effect ($p > 0.05$) on seed multiple index (see Appendix A2).

Table 4.3. Effects of operating speed, hopper fill level and their interaction on multiple index (MULI, %).

Parameter	Source of variation				
	Speed level	Seed type			
		Maize			
MULI (%)	V_1	15.391			
	V_3	16.978			
	V_5	17.718			
	Hopper filling level				
	H_{25}	16.616			
	H_{50}	16.322			
	H_{75}	16.889			
	H_{100}	16.957			
	Interaction(V *H)				
	Speed level	H_{25}	H_{50}	H_{75}	H_{100}
	V_1	15.463	15.000	15.587	15.513
	V_3	16.853	16.693	17.123	17.243
	V_5	17.530	17.273	17.957	18.113

The effects of the prototype planter speed, level of hopper filling and the combined effect of the two on percent of seed multiple index are given in Table 4.3 Figure 4.2 shows the relation between planter forward speed and percent of seed multiple index. As can be seen from Table

4.3 and Appendix A2, the effect of operational speed were significant. The combined effect of level of hopper filling and forward speed on percent of seed multiple index had no significant effect.

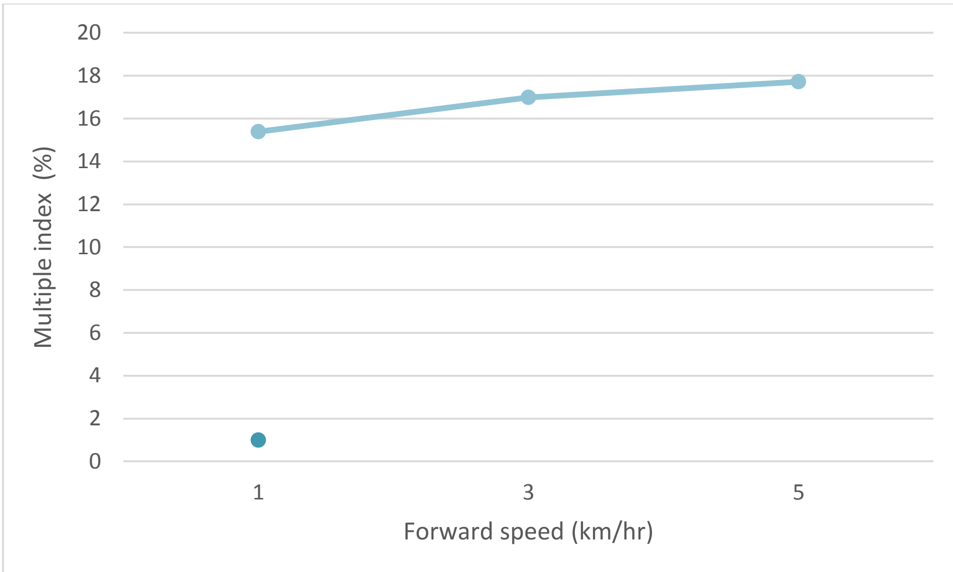

Fig. 4.2 Effects of planter forward speeds on seeds multiple indices

The highest percent seed multiple index occurred at planter forward speed of 5 km/hr. The lowest values were recorded at planter forward speed of 1 km/h. The level of hopper fill did not have any significant effect at $p > 0.05$ on percent seed multiple index (Table 4.3 and Appendix A2).

4.2.2.3. The quality of seed feed index

The analysis of variance (ANOVA) revealed that planter forward speed had significant effect ($p < 0.05$) on quality of feed index whereas, hopper loading level, the interaction of planter forward speed and hopper loading level had no significant effect ($p > 0.05$) on quality of feed index (see Appendix A3).

Table 4.4 shows the effects of operational speed of the planter and hopper fill level on percent of quality of seed feed index. Figure 4.3 shows the relation between planter linear speed and percent of quality of seed feed index. The forward speed of the planting machine had significant effect on the percent quality of seed feed index at the planter speed of 5 km/hr. The level of seed fill in the hopper was not statistically significant on the quality seed feed index (Appendix A3). This clearly indicated that the forward speed of the planter, i.e. the speed of the metering mechanism, had detrimental effect on the percent quality of seed feed index (percent cell fill) (Culpin, 1987 and Nielsen, 1995).

Table 4.4. Effects of operating speed, hopper fill level and their interaction on quality of feed index (QTFI, %).

Parameter	Source of variation				
	Speed level	Seed type: Maize			
QTFI (%)	V_1	80.748			
	V_3	78.170			
	V_5	76.152			
	Hopper filling level				
	H_{25}	78.100			
	H_{50}	78.626			
	H_{75}	78.283			
	H_{100}	78.418			
	Interaction(V *H)				
	Speed level	H_{25}	H_{50}	H_{75}	H_{100}
	V_1	80.097	81.447	80.610	80.840
	V_3	77.977	78.363	78.117	78.223
	V_5	76.227	76.067	76.123	76.190

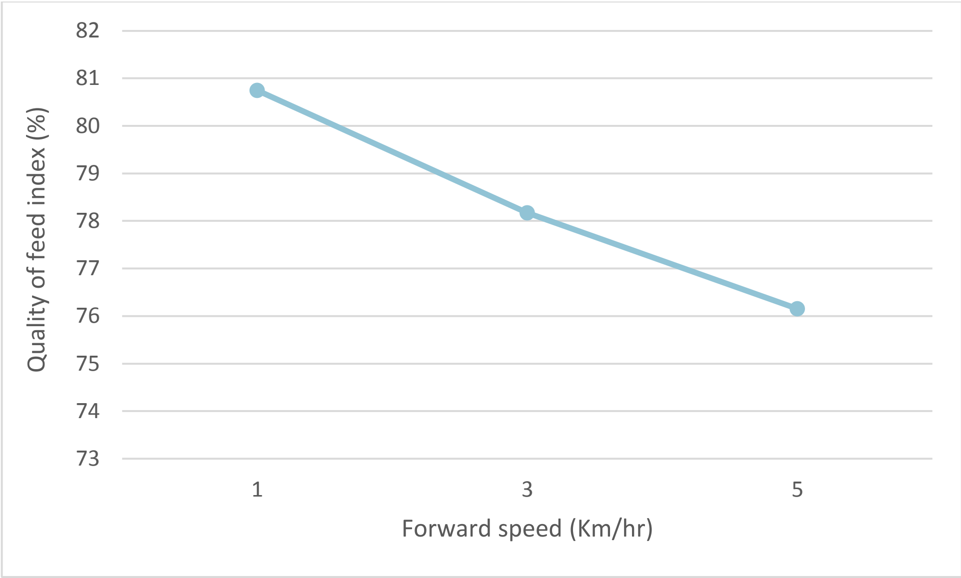

Fig. 4.3 Effects of planter forward speeds on quality of seed feed indexes

4.2.2.4. The seed precision index

The analysis of variance (ANOVA) revealed that planter forward speed had significant effect ($p < 0.05$) on precision in seed spacing whereas, hopper loading level and the interaction of treatments had no significant effect ($p > 0.05$) on precision in seed spacing (see Appendix A4).

Table 4.5 show the effects of operational speed of the planter, hopper fill level and seed type on mean percent seed precision index. Figure 4.4 shows the relation between planter linear speed and percent seed precision index. The results indicated that planter forward speed had significant effect on the percent seed precision index. Nonetheless, level of seed in the hopper did not have significant effect on the percent seed precision index. The combined effect of seed level in the hopper and forward speed of the planter, on the percent seed precision index, was significantly difference at the planter forward speed of 5 km/hr (Appendix A4).

Table 4.5. Effects of operating speed, hopper fill level and their interaction on seed precision index (%).

Parameter	Source of variation				
		Seed type			
	Speed level	Maize			
QTFI (%)	V_1	14.667			
	V_3	16.091			
	V_5	16.754			
	Hopper filling level				
	H_{25}	15.701			
	H_{50}	15.723			
	H_{75}	16.004			
	H_{100}	15.920			
	Interaction(V *H)				
	Speed level	H_{25}	H_{50}	H_{75}	H_{100}
	V_1	14.557	14.440	14.907	14.763
	V_3	15.880	16.110	16.107	16.267
	V_5	16.667	16.620	17.000	16.730

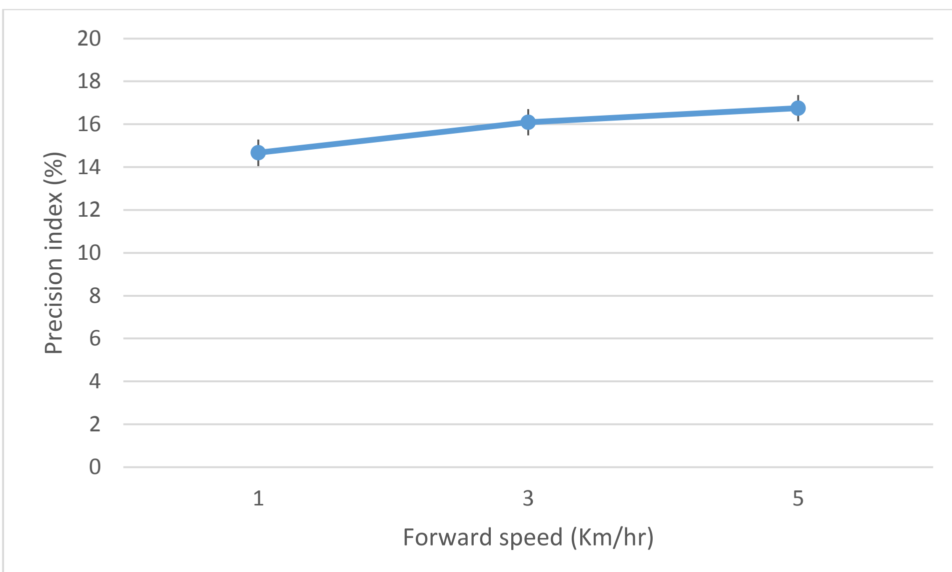

Fig. 4.4 Effects of planter forward speeds on percent seed precision index

The percent seed precision index, at the planter linear operating speeds of 1, 3 and 5 km/hr, were 14.667, 16.091, 16.754 respectively. This result clearly indicated that planter linear forward speed greater than 3 km/hr would result in seed spacing variations of over 16%. However, a practical upper limit for precision is 29%. Lower values for the precision indicate better performance compared to higher values (Kachman and Smith, 1995).

4.3. Field efficiency and field capacity of the planter

The field capacity and field efficiency of the prototype planter were determined as described in section 3.3.16.3. The mean field capacity and efficiency of the prototype planter were 0.21 ha/hr and 86 %, respectively. Considering the recommendations by Kepner *et al. (*1978) for planters, the field efficiency of the prototype planter is within the acceptable level.

4.4. Depth of Planting

The mean depth of seed placement achieved in the field was 4.6$\pm$ 0.3 cm. The depth of planting was less than the desired depth of planting of 5 cm as recommended for maize by agronomists. However, the deviation and the variability being too small and with acceptable range, it could be easily adjusted to the desired depth of planting by raising or lowering the furrow opener of the planter.

4.5. Stand Count

To avoid the rescue of non-germinating seeds and seed misses, the planter was designed to drop two seeds per hill. Considering two seeds per hill, the desired number of plants, within a row of 2 m long, for maize were 16. The stand count was made after 15 days of planting. The mean number of plants within rows of 2 m length for maize plant were 17.21$\pm$ 1.88. The number of plants were slightly higher than the recommended and the excess plants should be thinned.

4.6. Economical Evaluation

To plant and fertilize using the prototype row planter, two persons were required; one to direct the donkey and the other to operate the machine. However, manual placement of seeds and fertilizer requires three persons; one to do the ploughing and the other two to plant and apply fertilizer. According to Melesse (2007), the time required to plant and fertilizes a hectare of land using manual method, with three persons, was 26 hours, while a single person, using the prototype planter, required only 4.77 hours/ha to do the same work. Hence, the time requirement per hectare is reduced by more than one-eighth and labour requirement reduced by the same amount when the prototype planter was used. However, the cost of the planter which is estimated to be 8,053.07 Birr (see Appendix C) 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, CONCLUSION AND RECOMMENDATION

5.1. Summary

This study focused on the design, fabrication and performance evaluation of a two row animal drawn planter for maize crop seed that is cheap, affordable by the rural farmers, easy to maintain and less laborious to use. The planter has the capability of delivering the seeds precisely with uniform depth in the furrow, and also with uniform spacing between the seeds.

Physical properties of seeds, i.e., length, width, thickness, volume, geometric diameter, sphericity and thousands seed weight, involved in the study were investigated to optimize the design of the planter's components. In the investigation, the sphericity of Melkassa 138 maize seed was found to be 71.56±7.10 indicating that the seed was more or less spherical. Hence, circular shaped metering roller cells were used in the design of the metering plate.

Randomly selected 50 maize seeds that had passed through the metering plate were examined and the numbers of mechanically damaged, i.e. bruised, skin removed or crushed seeds were counted. The mean percent seed damage was found to be 1.01± 0.37%. The mean percentage germination was 94.58±0.21. Melkassa 138 maize seed variety had a mean percent germination rate of 95 %. Hence, the result was acceptable.

The planter forward speed and the interaction of planter forward speed with hopper loading level had significant effect ($p < 0.05$) on seed miss index. Operational speed had significant effect on percent of miss index at $p < 0.05$. Increasing speed of operation from 1 km/hr to 5 km/hr had increased the percent miss index. The level of seed in the hopper, i.e. level of filling, had significant effect on percent miss index. However, the effect was dominantly due to variation in speeds than hopper level of filling.

The planter forward speed showed significant effect ($p < 0.05$) on seed multiple index whereas, hopper loading level, and the interaction of planter forward speed and hopper loading level had no significant effect ($p > 0.05$) on seed multiple index. The highest percent seed multiple index occurred at planter forward speed of 5 km/hr. The lowest values, of the same, were recorded at planter forward speed of 1 km/h. The level of hopper fill did not have any significant effect at $p > 0.05$ on percent seed multiple index.

Forward speed had significant effect ($p < 0.05$) on quality of feed index whereas, hopper loading level, the interaction of planter forward speed and hopper loading level had no significant effect ($p > 0.05$) on quality of feed index. The forward speed of the planting machine had significant effect on the percent quality of seed feed index at the planter speed of 5 km/hr. The level of seed fill in the hopper was not statistically significant on the quality seed feed index. This clearly indicated that the forward speed of the planter, i.e. the speed of the metering mechanism, had detrimental effect on the percent quality of seed feed index.

The planter forward speed had significant effect ($p < 0.05$) on precision in seed spacing whereas, hopper loading level and the interaction of treatments had no significant effect ($p > 0.05$) on precision in seed spacing. Planter forward speed had significant effect on the percent seed precision index. Nonetheless, level of seed in the hopper did not have significant effect on the percent seed precision index. The combined effect of seed level in the hopper and forward speed of the planter, on the percent seed precision index, was significantly difference at the planter forward speed of 5 km/hr.

The mean field capacity and efficiency of the prototype planter were 0.21 ha/hr and 86 %, respectively. The field efficiency of the prototype planter, as recommended by Kepner *et al. (*1978) for planters, is within the acceptable level. The mean depth of seed placement achieved in the field was 4.6$\pm$ 0.3 cm. The depth of planting was slightly less than the desired depth of planting of 5 cm and could be easily adjusted to the desired depth. The mean number of plants within rows of 2 m length for maize plant were 17.21$\pm$ 1.88. The number of plants were slightly higher than the recommended, 16 plants per two meter length, and within the acceptable level.

The cost of the planter which is estimated to be 8,053.07 Birr 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.

5.2. Conclusion

A two-row donkey drawn maize row planter has been designed and fabricated with locally available materials to match the need and alleviate the difficulties of rural, small and medium scale farmers. The planter meters an average of two seeds per discharge with minimal or no damage of the seeds. It is simple and does not require any special skill to operate. The performance testing and evaluation of the prototype planter in terms of percent seed miss index, percent seed multiple index, percent quality seed feed index, percent seed precision index, depth of planting, optimum plant population, field capacity, field efficiency, labour cost and economics of owning and operating the machine is acceptable. The force required to pull the planter is less than the pull performance of the donkey so it can easily be pulled by the animal. With proper attention to its maintenance which may include; regular lubrication of moving parts, replacement of worn-out/damaged parts, cleaning and proper storage after use, this equipment will serve and adequately alleviate the farmers difficulties in maize production. Most importantly, the prototype planter can be efficiently, effectively and economically used by the majority of Ethiopian small holder farmers.

5.3. Recommendations

Following are the recommendations for operation of the low cost maize planter:

1. Adjustable seed metering mechanism should be used to use the planter for different maize varieties and crops.
2. Calibration of the seed metering device should be done accurately to get right seed rate and seed spacing.
3. A single shaft should be used as a wheel and metering shaft instead of chain and sprocket arrangement.
4. Consideration should be made to reduce the weight and cost of the planter.
5. The row planter is needed to be tested and demonstrated in the farmer's field.
6. Promotion and dissemination of the technology has to be done to end users.

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APPENDIX

Appendix A. Analysis of Variance

Appendix A1. Analysis of variance (Split-Plot design) of miss index (MISI) of seed spacing

Analysis of Variance Table for MISI

Source	DF	SS	MS	F	P
REP	2	0.0015	0.0008		
HOPPER	3	2.1823	0.7274	481.10	0.0000
Error REP*HOPPER	6	0.0091	0.0015		
SPEED	2	31.0600	15.5300	11480.1	0.0000
HOPPER*SPEED	6	1.4905	0.2484	183.63	0.0000
Error REP*HOPPER*SPEED	16	0.0216	0.0014		
Total	35	34.7651			

Grand Mean 4.9475
CV(REP*HOPPER) 0.79
CV(REP*HOPPER*SPEED) 0.74

LSD All-Pairwise Comparisons Test of MISI for SPEED

SPEED	Mean	Homogeneous Groups
5	6.1300	A
3	4.8517	B
1	3.8608	C

Alpha 0.05 Standard Error for Comparison 0.0150
Critical T Value 2.120 Critical Value for Comparison 0.0318
Error term used: REP*HOPPER*SPEED, 16 DF
All 3 means are significantly different from one another.

LSD All-Pairwise Comparisons Test of MISI for HOPPER

HOPPER	Mean	Homogeneous Groups
H25	5.2844	A
H50	5.0522	B
H75	4.8278	C
H100	4.6256	D

Alpha 0.05 Standard Error for Comparison 0.0183
Critical T Value 2.447 Critical Value for Comparison 0.0449
Error term used: REP*HOPPER, 6 DF
All 4 means are significantly different from one another.

LSD All-Pairwise Comparisons Test of MISI for HOPPER*SPEED

HOPPER	SPEED	Mean	Homogeneous Groups
H50	5	6.6600	A
H25	5	6.2433	B
H75	5	5.9200	C
H100	5	5.6967	D
H25	3	5.1700	E
H50	3	4.9433	F
H75	3	4.7600	G
H100	3	4.5333	H
H25	1	4.4400	I
H75	1	3.8033	J
H100	1	3.6467	K
H50	1	3.5533	L

```
Comparisons of means for the same level of HOPPER
  Alpha              0.05     Standard Error for Comparison  0.0300
  Critical T Value  2.120     Critical Value for Comparison  0.0637
  Error term used: REP*HOPPER*SPEED, 16 DF
Comparisons of means for different levels of HOPPER
  Alpha              0.05     Standard Error for Comparison  0.0306
  Critical T Value  2.237     Critical Value for Comparison  0.0685
  Error terms used: REP*HOPPER and REP*HOPPER*SPEED
All 12 means are significantly different from one another.
```

Appendix A2. Analysis of variance (Split-Plot design) of multiple index (MULI) of seed spacing

Analysis of Variance Table for MULI

Source	DF	SS	MS	F	P
REP	2	0.0421	0.0211		
HOPPER	3	2.2620	0.7540	69.87	0.0000
Error REP*HOPPER	6	0.0647	0.0108		
SPEED	2	33.9400	16.9700	2793.42	0.0000
HOPPER*SPEED	6	0.2754	0.0459	7.55	0.0006
Error REP*HOPPER*SPEED	16	0.0972	0.0061		
Total	35	36.6815			

```
Grand Mean 16.696
  CV(REP*HOPPER) 0.62
  CV(REP*HOPPER*SPEED) 0.47
```

LSD All-Pairwise Comparisons Test of MULI for SPEED

SPEED	Mean	Homogeneous Groups
5	17.718	A
3	16.978	B
1	15.391	C

Alpha 0.05 Standard Error for Comparison 0.0318
Critical T Value 2.120 Critical Value for Comparison 0.0675
Error term used: REP*HOPPER*SPEED, 16 DF
All 3 means are significantly different from one another.

LSD All-Pairwise Comparisons Test of MULI for HOPPER

HOPPER	Mean	Homogeneous Groups
H100	16.957	A
H75	16.889	A
H25	16.616	B
H50	16.322	C

Alpha 0.05 Standard Error for Comparison 0.0490
Critical T Value 2.447 Critical Value for Comparison 0.1198
Error term used: REP*HOPPER, 6 DF
There are 3 groups (A, B, etc.) in which the means
are not significantly different from one another.

LSD All-Pairwise Comparisons Test of MULI for HOPPER*SPEED

HOPPER	SPEED	Mean	Homogeneous Groups
H100	5	18.113	A
H75	5	17.957	A
H25	5	17.530	B
H50	5	17.273	C
H100	3	17.243	C
H75	3	17.123	C
H25	3	16.853	D
H50	3	16.693	D
H75	1	15.587	E
H100	1	15.513	E
H25	1	15.463	E
H50	1	15.000	F

Comparisons of means for the same level of HOPPER
Alpha 0.05 Standard Error for Comparison 0.0636
Critical T Value 2.120 Critical Value for Comparison 0.1349
Error term used: REP*HOPPER*SPEED, 16 DF
Comparisons of means for different levels of HOPPER
Alpha 0.05 Standard Error for Comparison 0.0714
Critical T Value 2.274 Critical Value for Comparison 0.1623
Error terms used: REP*HOPPER and REP*HOPPER*SPEED
There are 6 groups (A, B, etc.) in which the means
are not significantly different from one another.

Appendix A3. Analysis of variance (Split-Plot design) of quality of feed index (QTFI) of seed spacing

Analysis of Variance Table for QTFI

Source	DF	SS	MS	F	P
REP	2	0.043	0.0214		
HOPPER	3	1.326	0.4419	25.92	0.0008
Error REP*HOPPER	6	0.102	0.0170		
SPEED	2	127.403	63.7016	6891.84	0.0000
HOPPER*SPEED	6	1.781	0.2968	32.11	0.0000
Error REP*HOPPER*SPEED	16	0.148	0.0092		
Total	35	130.803			

Grand Mean 78.357
CV(REP*HOPPER) 0.17
CV(REP*HOPPER*SPEED) 0.12

LSD All-Pairwise Comparisons Test of QTFI for SPEED

SPEED	Mean	Homogeneous Groups
1	80.748	A
3	78.170	B
5	76.152	C

Alpha 0.05 Standard Error for Comparison 0.0392
Critical T Value 2.120 Critical Value for Comparison 0.0832
Error term used: REP*HOPPER*SPEED, 16 DF
All 3 means are significantly different from one another.

LSD All-Pairwise Comparisons Test of QTFI for HOPPER

HOPPER	Mean	Homogeneous Groups
H50	78.626	A
H100	78.418	B
H75	78.283	B
H25	78.100	C

Alpha 0.05 Standard Error for Comparison 0.0616
Critical T Value 2.447 Critical Value for Comparison 0.1506
Error term used: REP*HOPPER, 6 DF
There are 3 groups (A, B, etc.) in which the means
are not significantly different from one another.

LSD All-Pairwise Comparisons Test of QTFI for HOPPER*SPEED

HOPPER	SPEED	Mean	Homogeneous Groups
H50	1	81.447	A
H100	1	80.840	B
H75	1	80.610	C
H25	1	80.097	D
H50	3	78.363	E
H100	3	78.223	EF
H75	3	78.117	FG
H25	3	77.977	G
H25	5	76.227	H
H100	5	76.190	H
H75	5	76.123	H
H50	5	76.067	H

```
Comparisons of means for the same level of HOPPER
  Alpha              0.05     Standard Error for Comparison  0.0785
  Critical T Value  2.120     Critical Value for Comparison  0.1664
  Error term used: REP*HOPPER*SPEED, 16 DF
Comparisons of means for different levels of HOPPER
  Alpha              0.05     Standard Error for Comparison  0.0889
  Critical T Value  2.277     Critical Value for Comparison  0.2023
  Error terms used: REP*HOPPER and REP*HOPPER*SPEED
There are 8 groups (A, B, etc.) in which the means
are not significantly different from one another.
```

Appendix A4. Analysis of variance (split- plot design) of precision (PREC) of seed spacings

Analysis of Variance Table for PREC

Source	DF	SS	MS	F	P
REP	2	0.5162	0.2581		
HOPPER	3	0.5968	0.1989	3.24	0.1028
Error REP*HOPPER	6	0.3687	0.0614		
SPEED	2	27.3037	13.6518	123.43	0.0000
HOPPER*SPEED	6	0.2824	0.0471	0.43	0.8512
Error REP*HOPPER*SPEED	16	1.7697	0.1106		
Total	35	30.8375			

```
Grand Mean 15.837
  CV(REP*HOPPER) 1.57
  CV(REP*HOPPER*SPEED) 2.10
```

LSD All-Pairwise Comparisons Test of PREC for HOPPER

```
HOPPER    Mean  Homogeneous Groups
H75     16.004  A
H100    15.920  AB
H50     15.723  AB
H25     15.701   B

Alpha              0.05     Standard Error for Comparison  0.1169
Critical T Value  2.447     Critical Value for Comparison  0.2859
Error term used: REP*HOPPER, 6 DF
There are 2 groups (A and B) in which the means
are not significantly different from one another.
```

LSD All-Pairwise Comparisons Test of PREC for SPEED

```
SPEED    Mean  Homogeneous Groups
    5  16.754  A
    3  16.091   B
    1  14.667    C

Alpha              0.05     Standard Error for Comparison  0.1358
Critical T Value  2.120     Critical Value for Comparison  0.2878
Error term used: REP*HOPPER*SPEED, 16 DF
All 3 means are significantly different from one another.
```

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

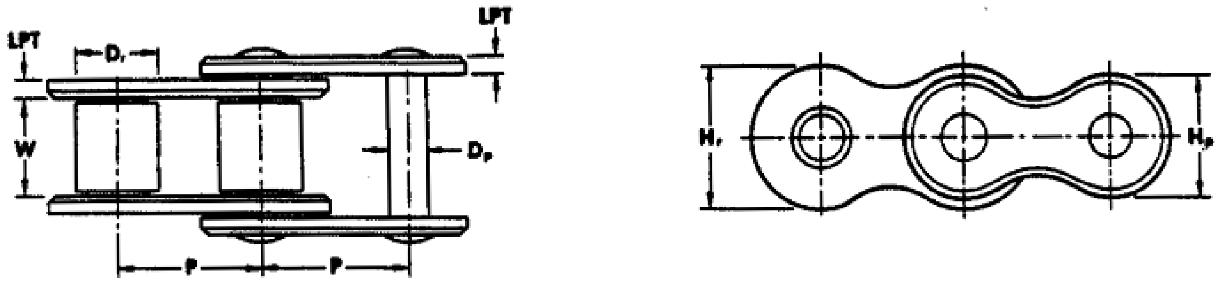
```
HOPPER SPEED    Mean  Homogeneous Groups
H75        5  17.000  A
H100       5  16.730  AB
H25        5  16.667  AB
H50        5  16.620  ABC
H100       3  16.267   BCD
H50        3  16.110    CD
H75        3  16.107    CD
H25        3  15.880     D
H75        1  14.907      E
H100       1  14.763      E
H25        1  14.557      E
H50        1  14.440      E

Comparisons of means for the same level of HOPPER
  Alpha              0.05     Standard Error for Comparison  0.2715
  Critical T Value  2.120     Critical Value for Comparison  0.5757
  Error term used: REP*HOPPER*SPEED, 16 DF
Comparisons of means for different levels of HOPPER
  Alpha              0.05     Standard Error for Comparison  0.2506
  Critical T Value  2.191     Critical Value for Comparison  0.5491
  Error terms used: REP*HOPPER and REP*HOPPER*SPEED
There are 5 groups (A, B, etc.) in which the means
are not significantly different from one another.
```

Appendix B. Material Type and Specification

Appendix B1. General Chain Dimensions, mm (inches)

***Identification, installation, lubrication and maintenance of power transmission roller chains in ANSI B29.1 and ANSI B29.3*, by permission of the American Chain Association, Rockville, MD.)**



Standard Chain No.	Pitch P	Max. Roller Diam. D_r	Nominal Width W	Nominal Pin Diam. D_p	Link Plate Thickness LPT	
					Standard Series	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 B2. Selected types of materials for construction of the prototype planter

No.	Name of part	Material
1	Frame and toolbar	Mild steel (MS)
2	Wheels	MS
3	Axle and shaft	MS
4	Seed box	MS sheet
5	Boot	MS
6	Furrow opener	MS
7	Seed tube	Plastic
8	Seed metering mechanism	MS
9	Bushes	Brass grade 3
10	Covering device	MS
11	Sprocket and gear	CI
12	Hitching mechanism	MS
13	Depth adjusting mechanism	MS
14	Feed adjusting mechanism	MS

Appendix C: Production Cost of Prototype Planter

Appendix C1. Raw material list and cost

No	Type of material	Standard size	Price (Birr)	Unit	Total Price
1	Sheet metal 1.5mm	1.5mmx1000mmx2000mm	650.00	906,823 mm^2	294.72
2	Sheet metal 2mm	2mmx1000mmx2000mm	770.00	84,362 mm^2	32.48
3	Sheet metal 3mm	3mmx1000mmx2000mm	1,500.00	19,514 mm^2	14.64
4	Sheet metal 6mm	6mmx1000mmx2000mm	2,610.00	283,040 mm^2	369.37
5	Square pipe (hollow)	20mmx20mmx3000mm	555.00	6,480mm	1198.80
6	Galvanized circular pipe (hollow)	Ø20x3000mm	485.00	3,870mm	625.65
7	Square bar	15mmx15mmx3000mm	403.00	800mm	107.47
8	Round bar Ø8	Ø8x3000mm	120.00	3,840mm	153.60
9	Round bar Ø20	Ø20x3000mm	598.00	2,220mm	442.52
10	Bearing		345.00	4pcs.	1380.00
11	Chain	6000mm	600.00	443mm	44.30
12	Sprocket	15 teeth	400.00	2pcs.	800.00
13	Hinge	2.5”	10.00	2pcs.	20.00
14	Metal bolt and nut	M-8x30	3.33	16pcs.	53.28
15	Metal bolt and nut	M-6x20	2.50	4pcs.	10.00
16	Electrode (pack)	Ø 2.5	130.00	1pack	130.00
Subtotal					**5,676.83**

Table C2. Machine and labor cost

No.	Type of machine	Machine Cost			Labour Cost		
		Working hour	Cost/hr	Cost	Working hour	Cost/hr	Cost
1	Universal metal cutting	3	10	30.00	3	6.25	18.75
2	Welding machine	10	5	50.00	10	6.25	62.5
3	Power hack saw	8	4	32.00	8	6.25	50
4	Lath machine	10	15	150.00	10	6.25	62.5
5	Rolling machine manual	1	3	3.00	1	6.25	6.25
6	Radial drill machine	2	3	6.00	2	6.25	12.5
7	Grinding machine	4	1	4.00	4	6.25	25
8	Bending machine	1	2.5	2.50	1	6.25	6.25
				277.50			**243.75**
	Subtotal						**521.25**

Table C3. Cost Summary

No.	Types of cost	Summary of cost
1	Raw material cost	**5,676.83**
2	Material Wastage (2.5% of 1)	**141.92**
3	Machine Cost	**277.50**
4	Labor cost	**243.75**
5	Overhead cost (5% of (3 + 4))	**26.06**
6	Profit (10% of (1+2+3+4+5))	**636.61**
7	Sells tax (15% of (1+2+3+4+5+6))	**1,050.40**
Selling Price (1+2+3+4+5+6+7)		**8,053.07**

Appendix Figure