

**DESIGN AND DEVELOPMENT OF TRACTOR MOUNTED POTATO
PLANTER**

MSc THESIS

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Design and Development of Tractor Mounted Potato Planter

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ENGINEERING**

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DEDICATION

This thesis manuscript is dedicated to my beloved father Eyasu Wada and mother Birtukan Babanto, who sacrificed much to bring me up to this level.

STATEMENT OF THE AUTHOR

The author declares that this thesis work is his authentic work and that all source of materials used for the thesis have been dully acknowledged. This thesis have been submitted in partial fulfillment of the requirements for an MSc degree at Haramaya University and distributed in the Haramaya University Library to be made available to borrowers under the rules of the library. The author solemnly declare that this thesis is not been submitted to any other institutions anywhere for the award of any academic degree, diploma, or certificate.

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BIOGRAPHICAL SKETCH

The author was born on October 24, 1989 in Sodo Town, Wolaita Zone, SNNPRS of Ethiopia, from his father Eyasu Wada and his mother Birtukan Babanto. He attended his elementary school education at Damot Woyde Woreda Primary School and his high school education at Bedessa Comprehensive Secondary and Preparatory School and then he joined Hawassa University in 2010 and graduated with BSc degree in Agricultural Engineering and Mechanization in July 2014. After his graduation, he was employed at Haramaya Institute of Technology as Assistant Lecturer in the Department of Agricultural Engineering. He started his MSc studies at Department of Agricultural Engineering, Haramaya Institute of Technology, Haramaya University.

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ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ANSI	American National Standards Institute
ASABE	American Society of Agricultural and Biological Engineers
ASAE	American Society of Agricultural Engineers
ASME	American Society of Mechanical Engineers
C.G	Center of Gravity
CSA	Central Statistical Agency
CV	Coefficient of Variation
d_g	Geometric Mean Diameter
D_w	Diameter of Ground Wheel
e	Eccentric distance from force applied to the center of gravity
EARC	Ethiopian Agriculture Research Center
EARO	Ethiopian Agriculture Research Organization
EFC	Effective Field Capacity
ETB	Ethiopian Birr
F'	Primary Shear Force
F''	Secondary Shear Force
FAO	Food and Agricultural Organization
FE	Field Efficiency
F_o	Average Soil Force Acting on the Furrow Opener
F_R	Resultant Force Acting on the Bolt
F_{RR}	Rolling Resistance Force
i	Gradient of the Field
LSD	Least Significant Difference
M_b	Bending Moment
MISSI	Miss Index
MS	Mild Steel
MULTI	Multiple Index

M_w	Weight of the Planter on Each Wheel
n	Number of Spokes
P	Rated Power
P_d	Design Power
P_p	Plant Population per Hectare
P_s	Plant Space
QFI	Quality of Feed Index
R_s	Row Space
S	Sphericity of Potato Tuber
SNNPRS	South Nation Nationalities and Peoples Regional State
T	Torque Produced on the Ground Wheel
T_{max}	Maximum Torque
Z	Maximum Wheel Sinkage

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DESIGN AND DEVELOPMENT OF TRACTOR MOUNTED POTATO PLANTER

ABSTRACT

Potato is the most important vegetable crop in developing countries. Potato cultivation is a labour intensive work. Human labor is still the main source of power used in agricultural works in Ethiopia. Thus, in manual method of planting there is high wastage of human energy, time and effort. This study was initiated to design, manufacture, test and performance evaluation of a prototype tractor mounted potato planter. The prototype planter consisted of main frame, hopper, casing, furrow opener, metering device, sprocket wheels, 3-point linkage, ground wheels, covering devices, solid shaft, and ball bearings with plunger blocks. The experimental design used was split-split plot at three forward speeds (2.5, 3.6 and 4.8 km/h), hopper fill level of (25%, 50% and 75%) and three tuber sizes (25-35, 35-45 and 45-55 mm) with three replications. Planting space was also maintained at 75.00 cm between rows and 30.00 cm between plants and the average depth of planting 12.50 cm. A tractor was used to carry out field test and the field was tilled to a depth of 25-30 cm and harrowed. The performance of planter was evaluated in terms of mean tuber spacing, coefficient of variation, multiple index, miss index and the quality of seed index. In field test, the performance of planter was also evaluated in terms of effective field capacity and field efficiency. The mean field capacity and field efficiency, were 0.20 ha/hr and 72.22%, respectively. Percent of visible mechanically damaged tubers using the planter were 0.93%, 1.23% and 1.48% for small, medium and large tuber, respectively. Tuber size, tractor forward speed and hopper fill level have significantly ($p < 0.05$) affected the mean tuber spacing. Use of tuber with size of 35.00-45.00 mm, forward speed of 3.6 km/hr and hopper fill level of 50% gave optimum planting space of 29.04 cm, 28.93 cm and 29.16 cm spacing uniformity than other combinations. The prototype planter performed the intended function of planting potato tuber at required row-to-row and plant-to-plant spacing satisfactory. The total power needed to propel prototype potato planter was found to be 10.54hp. This machine is single row planter effort must be made to make multi-row planter.

Keyword: Efficiency; Evaluation; Potato planter; Planter performance;

1. INTRODUCTION

Potato is the most important vegetable crop in developing countries, and its production is expanding more rapidly than other food crops (Scott *et al.*, 2000). Hundreds of million people in developing countries depend on potatoes for their survival (FAO, 2008).

In Ethiopia, the total area under potato production reached 69,784 ha, even if, the edaphic and climatic conditions are suitable for potato production in Ethiopia, the national average production is low as 8 t ha⁻¹ (Medhin *et al.*, 2000). The productivity of the crop in the country is low compared to the world average of 17.00 t/ha and that of Africa which is 11.00 t/ha (Adane *et al.*, 2010).

Low level of mechanization, poor crop management practices and poor research extension linkages are among the key factors contributing to this low acreage yield of potato. The low productivity can be attributed to many factors, but lack of quality potato seeds, lack of machinery for seedbed preparation, planting, cultivation and harvesting are the major constraints (Endale *et al.*, 2008a; Berga *et al.*, 1994).

Human labor is still the main source of power used in agricultural works in Ethiopia. Thus, in manual method of planting, there is high wastage of human energy, time and effort, low seed placement, spacing efficiencies and it is tedious.

In manual method of planting, the soil is tilled and furrows are made by oxen drawn indigenous plough. To carry out the planting tasks, a person is required to control the straightness of the furrow, and another person is required to manually drop the potato tubers, and finally ridging is made manually by using hand tool; as a result; the required depth and spacing uniformity are not maintained at all (Kumar *et al.*, 2015; Soyoye *et al.*, 2016).

All these result in low productivity of yield and tiredness to the farmers of Ethiopia. However, applying modern farming technologies and improved farm implements surely increase the productivity. Hence, mechanizing and modernizing farming system including planting in Ethiopia is the order of the day.

Experiments have shown that the use of improved agricultural implements including planting machinery not only increase production but also reduce manual drudgery and improve man-machine compatibility. The improved potato varieties together with modern planting machine would give three to four fold yield advantage as compared to local varieties established using traditional manual planting practices (Singh, 1977).

Now a day's semi- automatic potato planters were introduced to the potato producing farmers. However, in semi-automatic potato planting machine, additional person required who set at the back of planter and manually pick tubers from hopper and feed it in to series of rotating cups. Nonetheless, the timeliness of operation was not achieved and farmers were still subjected to drudgery work.

Furthermore, the introduction of improved automatic potato planter is significantly reduce drudgery of the farmers and enhances the potato production. Since, high accuracy of plant spacing is results in high yield and a uniform sorting of the tubers at harvest (McPhee *et al.*, 1996; Pavek and Thornton, 2003).

This prototype potato planter was able to maintain effective planting and row space, minimizing the labor requirement, simple, affordable, mounted and operated by 30hp mini tractor.

1.1. Objectives of the Study

1.1.1. General objective

-  To design, manufacture, test and performance evaluation of a prototype tractor mounted potato planter.

1.1.2. Specific objectives

-  To conduct rigorous component design and manufacture a prototype potato tubers planter;
-  To evaluate field capacity and field efficiency of prototype potato tubers planter;
and
-  To evaluate owning and operating cost of the prototype planter.

2. LITERATURE REVIEW

2.1. Methods of Potato Cultivation in Ethiopia

Ethiopia is one of the principal potato producing countries in Africa and probably displays a unique position for having the highest potential area for cultivating potatoes (EARO, 2000). Potato is the second most important tuber crop grown in the country next to 'Enset' in terms of area coverage (Girma, 2001).

The crop is cultivated approximately by 1.13 million small-scale farmers (CSA, 2011). Potato is produced twice a year in Ethiopia both in *Belg* (February to May) and *Meher* (from June to October) growing seasons (CSA, 2013/2014). This is because of Ethiopia has good climatic and edaphic conditions for potato production (Endale *et al.*, 2008a).

Compared to cereal crops, potato is short duration crop that can reach within 90-120 days in Ethiopia (Endale *et al.*, 2008b). The crop became a very important crop in many parts of Ethiopia and its production increased from year to year (Gebremedhin *et al.*, 2008).

Currently, it is one of the major food crops grown in the high and mid altitudes of Ethiopia and serving as food and sources of income for farmers specially during food shortage and when grains depleted from stores (Girma *et al.*, 2004).

Human labor is still the main source of power used in agricultural work in developing countries. In traditional method of potato planting, farmers covers less area in more time, 2142 man-h/ha is required in potato planting and ridging in manual operation whereas 544 man-h/ha by tractor drawn potato planter (Singh and Singh, 2000).

In manual method of potato planting, potato is placed in the furrow by hand and ridging by spade, due to this; depth of covering of soil is not maintained up to required depth and uniformity is not maintained. The variations in depth of seed placement resulted into production of green potato, which are not fit for human consumption.

In some regions, fertilizer is mixed with seedbed preparation. Potato is planted by forming a furrow by bullock drawn indigenous plough in the tilled soil. Potatoes are placed in furrow and then it is covered with soil mass and ridge is formed above it using indigenous plough.

2.2. The Importance of Potato Tuber in Ethiopia

Potato is a very important food and cash crop in Ethiopia, especially in the highland and mid altitude areas. It serves as food and cash crop for small-scale farmers, occupies the largest area compared to other vegetable crops and produces more food per unit area and time compared to cereal crops (Yigzaw *et al.*, 2008).

As the population grows rapidly, increased productivity of potatoes can improve the livelihood of smallholder potato producers and is required to meet the growing demand (Gildemacher, 2012). In addition, potato is regarded as high-potential food security crop because of its ability to provide a high yield of high-quality product per unit input with a shorter crop cycle than major cereal crops like maize (Adane *et al.*, 2010).

As a result, it is becoming an increasingly important source of rural employment, income, and food for growing populations (Ephrem, 2015). The tuber is known to supply carbohydrate, high quality protein, and substantial amounts of essentials vitamins, minerals, and trace elements (Horton and Sawyer, 1985).

Moreover, in Ethiopia potato production serves as a means to overcome food shortage ‘hungry months’ since it matures before the harvest of other food crops such as cereals (Sanginga *et al.*, 2009).

2.2.1. Seedbed preparation for potato production

Preparation of land for planting is common for both manual procedure and potato planting machine. Tillage aims to create a soil environment favorable to plant growth (Klute, 1982).

2.2.2. Seed emergence and plant population

The seedling emergence is mainly influenced by the soil type, the physical condition of soil, the depth of planting, the intimacy of contact between the seed and the soil, the degree of soil compaction above the seed, and formation of surface crust after planting (Kepner *et al.*, 1978). Berga *et al.* (1994) from their previous result concluded that stem number per plant and tuber number per plant are positively correlated.

Plant density in potato affects some of the important plant traits such as total yield, tuber size distribution and quality (Zahilie *et al.*, 2011). The planting rates of potato tubers are between 900 and 1700 kg/ha (Kepner *et al.*, 1978). In practice, the needs of the individual plants have to be balanced against the requirement to maximize crop yield (Wollin *et al.*, 1987).

The optimum plant population per hectare can be calculated using Eqn. (1) for recommended plant spacing (row to row and plant spacing) (Olaoye and Bolufawi, 2001);

$$P_p = \frac{10,000m^2}{P_s \times R_s} \quad 1$$

where: - P_p = plant population per hectare, tuber/ha
 P_s = plant space, m
 R_s = row space, m

2.2.3. Planting space

One of the most important management practices of potato production is plant spacing. These parameters depend on the performance of the metering mechanism of the seed planter. Uniform seed spacing and depth is propitious to higher emergence rate and increasing yield by decreasing competition between plants for available light, water and nutrients (Karayel and Ozmerzi, 2002).

The research system of Ethiopia recommends seed tuber spacing of 75.00 cm between rows (ridges) and 30.00 cm between plants for ware potato production, but 60.00 cm between rows (ridges) and 20.00 cm between plants for seed tuber production (EARO, 2004). On the other hand, farmers in Ethiopia often use even closer spacing than national recommended 75.00 cm between rows and 30.00 cm between plants for both ware and seed potatoes production (Mulatu *et al.*, 2005).

Therefore, potato seed tuber spacing in eastern Ethiopia does not account for varietal differences as well as whether the potato production is meant for ware or seed tubers. Thus, no efforts have been made to determine the optimum spacing for the different varieties. High accuracy of plant spacing results in high yield and a uniform sorting of the tubers at harvest (McPhee *et al.*, 1996; Pavek and Thornton, 2003).

2.2.4. Planting depth

Planting depth is a major determinant of seedling emergence and hence one of the most important operational requirements of a planting machine (Rainbow *et al.*, 1992). Appropriate planting depth is one of the main agronomic requirements for potato production; this is because, potato tubers, which are economical part of the crop, are produced underground.

According to Pavek and Thornton (2009), planting potato in shallow depth resulted in declining marketable yield and gross income from potato crop production. On contrary, deeper planting help to overcome tuber greening, exposure of tuber to external environments, water shortage and to reach the expected yield (Pavek and Thornton, 2009). According to EARO (2004), 10.00– 15.00 cm planting depth used for all varieties released so far in Ethiopia and serve as standard recommendation in the area of potato production for ware or seed.

2.3. Physical Properties of Potato Tuber

Seed flow through a planter is dependent on size, shape, sphericity, true density and angle of repose of seeds. The physical properties namely, length, breadth, surface area, roundness, equivalent diameter, sphericity, seed weight, true density and angle of repose are design

parameters for a planter (Jayan and Kumar, 2004). Physical properties (shape, size, sphericity, density, volume and angle of repose) strongly influence the efficiency of agricultural equipment (Kutzbach, 1989). The average length, width, thickness, arithmetic and geometric mean diameters, surface area, volume, thousand grain mass and angles of repose increased as the moisture content increased from 10 % to 25 %.

2.3.1. Sizes of potato tuber for production

The seed spacing uniformity is affected by the tuber characteristics (size and shape) as well as machine s' forward speeds (Sieczka *et al.*, 1986). Hence, appropriate seed tuber size has very important implication on potato planters. Although all sizes of seed potatoes can grow into a crop, seed growers should only plant tubers range from 25.00-55.00 mm in diameter or 40-75 g in weight (Lung'aho *et al.*, 2007).

Tubers might be categorized in different way based on diameter of the tubers using calipers or mass of the tubers. In most case, categorization based on diameter of are reported as tubers less than 25.00 mm are under sized (very small), those between 25.00-35.00 mm are small, 35-55.00 mm are medium and greater than 55.00 mm are large and tubers which are healthy with a size more than or equal to 25.00 mm are generally considered as marketable tuber (Hassanpanah *et al.*, 2009).

According to Sanli *et al.* (2015) report effect of in-row spacing on tuber size was significantly ($P > 0.01$) important and large sized tuber (>55.00 mm) yield increased with the increase in-row spacing, medium (35.00-55.00 mm) and small sized (25.00-35.00 mm) tuber yield decreased. Undersized and small sized tubers are less desired because of the low market prices (Hossain *et al.*, 2011). Medium sized tubers are the most desired ones for their seed value and higher market prices.

2.3.2. Repose angle of potato tuber

The angle of repose of seeds was determined by the method explained by Waziri and Mittal, (1983). The cylinder was placed on a horizontal surface and being filled with potato tubers.

Then, lifted gently until maximum height was reached and the height of seed heap was noted; thus, the vertical height (height of cone) and horizontal spread of tubers at the bottom of the heap could be measured. The experiment was replicated three times for each tuber size and the average values were computed.

2.4. Modern Potato Planters

Now a days in modern farming, two types of planter available such as semi- automatic and automatic planter. In semi-automatic cup- belt metering system; the planting machine require additional person who set at the back of planter and manually pick tubers from hopper and feed it in to series of rotating cups. Nonetheless, the timeliness of operation was not achieved and farmers were still subjected to drudgery work.

Singh (2004) conducted study on tractor mounted semi-automatic two-row belt driven potato planter. Potato planting was done manually; manual operation results in varying and non-uniform plant stand, requires large labor force in field preparation and planting, besides being less time-efficient due to unavoidable drudgery and competing demand for labors.

In addition, automatic potato planters with cup - belt-metering system was introduced, but due to slippage and lower power, transmission of the belt the machine was found to be not efficient. In addition, vibration of belt during planting operation was one of problem related to these types of potato planters. Previous studies showed that potato planters where the low performance of these machines may be due to the high of forward speed (Sieczka *et al.*, 1986). On the other hand, the price of imported planters has gone beyond the purchasing ability of most of our farmers.

As a solution to slippage problem encountered with belt cup metering system, a prototype tractor mounted potato tuber planter equipped with chain cup metering. Since, chain has higher power transmission efficiency than belt and slippage is zero (Khurmi and Gupta, 2005). This prototype potato planter was able to maintain effective planting and row space, minimizing the labor requirement, simple, affordable, mounted and operated by 30hp mini tractor.

2.4.1. Automatic potato planter and its component parts

The placement of tuber in the soil plays an important role in the good germination of the tuber. Automatic potato planters are designed to meter one tuber at a time and to place tubers in a furrow at predetermined spacing and depth. Automatic planters are available in many variations, but four functions are always included; these are open furrows to the desired depth, meter tubers and drop tubers into the furrow at uniform intervals, cover the tuber, and firm the soil against the tuber (Kepner *et al.*, 1978).

2.4.1.1. Row crop planter frame

A frame is the skeletal structure of a planter on which all other components are mounted. The two design factors considered in the determination of the material required for the frame are the weight and strength. The frame of farm machine must be as light as possible to reduce cost, soil compaction and propelling power but strong enough to resist the shocks due to rough fields or obstacles. Smith and Wilers (1977) had given some guidelines for the fabrication of a planter frame. The frame was usually made of mild steel angle iron.

2.4.1.2. Row crop planter hopper

The hopper has a shape of frustum of a rectangular truncated pyramid manufactured from 2.00 mm thick mild steel sheet metal as recommended by Smith and Wilers (1977) and Ibukun *et al.* (2014).

2.4.1.3. Seed metering mechanisms

Accuracy of row plant spacing depends on the ability of the seed metering mechanism. Currently, the common metering mechanisms used in potato planters include cup-chain, air suction and belt conveyor. Kepner *et al.* (1955) reported that the percent of cell fill for a given planter was influenced by such factors as the maximum seed size in relation to cell size, the range of seed size, the shape of seeds, the shape of cells, the exposure time of a cell to seed in the hopper and the linear speed of the cell.

Based on the drive type, cup style can be divided into cup-chain and cup-belt. Cup-belt is often utilized in large tractors because of its strong demand for power, as demonstrated by the highly reliable German Grimme GL series potato planter that combines mechanical, electrical, hydraulic, and controller features with high reliability (Al-Gaadi and Marey, 2011). Cup-chain is utilized in small and medium tractors with low power demands.

Cup metering is the most widely used metering device because of its high reliability, low cost and adjustable plant spacing. The cup feed mechanism also exhibits minimum seed damage compared to other common types of seed metering devices (Shaffi and Holmes, 1990).

A chain transmission system from ground wheel with sprockets and chain was provided for driving the seed metering device. Cup size has a significant effect on metering performance. Experience had indicated that the cell diameter or length should be about 10 percent greater than the maximum seed dimension and the cell depth should be about equal to the average seed diameter or thickness.

The chain-spoons type seed metering exposes the tuber pieces to friction between its surface and the conveyor guide until it leaves the metering unit. The tuber pieces would be exposed to damage every revolution of the feeding system. The spoons were replaced with simple cups. They are designed to convey the tuber and to keep it from movement until exiting from the metering system.

Bader (2002) evaluated three potato feeding systems (semi-automatic chain, semi-automatic tray and automatic chain cup) to determine the optimum operational requirements and to select the most effective system. Accordingly, automatic chain cup planter was found to be the best.

2.4.1.4. Furrow openers and its rake angle

The types of furrow openers used vary with soil and operating conditions (Chaudhuri, 2001). A common type of furrow opener for potato planter is shoe/sweep type furrow opener (Kepner *et al.*, 1978).

The furrow characteristics influence the germination and emergency of crop under different soil conditions. The draft requirements of the furrow openers depends upon soil conditions, type of furrow opener as well as speed and depth of operation.

Width of furrow opener is another design factor affecting draught of the opener as well as soil cover over the seed during sowing operation. Chaudhuri (2001) reported that for both wet and dry soil conditions, the force acting on the furrow opener increases with increasing width of opener. Darmora and Pandey (1995) also reported that the draft force is related to tool width.

Increases in the depth of furrow opener increase the draft force and affect the recovering of soil in the furrows. Chaudhuri (2001) indicated that the optimum rake angle of furrow openers, for least draught requirement, should be between 25° and 30°.

2.4.1.5. Ground wheel diameter selection

Diameter selection is mainly based on machine height and the width of wheel depends on type of soil and wheel sinking. Yadav and Kumar (1992) tested a manually operated multi crop planter with plain and peg type wheels to evaluate performance.

The result showed improved performance of planter with peg type wheels, wheel slip was reduced as compared to plain wheels. Verma (1986) reported that diameter of power transmission wheels of animal drawn and tractor drawn seed cum fertilizer drill and planter ranges from 22.5.00 to 40.00 cm and 40.00 to 60.00 cm, respectively. According to Ismail (2004) the recommended diameter of ground wheel for belt drive potato planter was 440.00 mm.

2.4.1.6. Covering devices

Potato tuber is planted in furrow and covering is made by forming ridge. The disks are used for covering and ridging; the angles vary from 42° to 45° (Ajit *et al.*, 2006).

2.4.1.7. Three – point hitch categories

Srivastava (1990) stated that the method of hitching also affects the rate of sowing. Hitching too low results the furrow openers and boots to drop seeds back and upward to the ground line. The forces transmitted through a hitch can affect the performance of both the tractor and planter.

From the total weight of planting machine, only 25 % of the weight is taken by tractor hydraulic system and the remaining 75% is carried by planter ground wheel during working condition (Sharma, 2010). Taylor *et al.* (1991) stated that a careful approach to matching tractors and implements could increase efficiency of operation and farm profitability.

The American Society of Agricultural Engineers (ASAE) standards for three point hitches specify all dimensions related to the three connecting points (two lower links and an upper one) between the implement and the tractor. The hitch dimensions that are standardized include hitch pin diameters, mast height, and lower hitch point spread and different ranges of maximum drawbar power have been standardized by ASAE (now ASABE) since 1959.

2.5. Testing and Performance Evaluation of the Row Crop Planter

The term “testing” is usually used in connection with an analysis of the behavior of a machine compared with well-defined standards under ideal and conditions (Johnson, 1985). In contrast, “evaluation” involves measurement of machine performance under real farm conditions.

Seed spacing uniformity is an important indicator in evaluating seed drill performance, because a uniform distribution of seeds can not only provide maximum space for each plant but also make for uniform root size, which can increase yields and reduce harvest loss (Zhao, 2010)

Tuber spacing uniformity is evaluated in terms of the mean tuber spacing (M), the coefficient of variation (CV %), the multiple index (MULTI %), the miss index (MISSI %) and the quality of feed index (QFI %) (Kachman and Smith, 1995). For common grain drills, a CV (%) of 20% is an acceptable seeding accuracy achieved by mechanical and pneumatic seeders when they

are performing well (Griepentrog, 2002). In addition, in field test the performance of planter is also evaluated in terms of actual field capacity (AFC), theoretical field capacity (TFC) and field efficiency (FE %).

 **Mean Tuber Spacing(M):-** mean tuber spacing can be calculated as Equ.(2);

$$M = \frac{G}{n} \quad 2$$

where:- G = grand total observation, cm
 n = total number of treatment

 **Coefficient of Variation (CV %):-** Coefficient of variation of tuber spacing was calculated as follows Equ.(3):

$$CV(\%) = \frac{SD}{M} \times 100\% \quad 3$$

where:- SD = is the standard deviation of tuber seed spacing
 M = is the mean tuber spacing, cm

 **Miss Index (MISI %):-** Miss index (MISSI, %) is the percentage of spacings greater than 1.5 times the theoretical spacing. The percentage of tuber miss index (MISI, %) was

 **Multiple index (MULTI %):-** Multiple index (MULTI, %) is the percentage of spacings that are less than or equal to half the theoretical

 **Quality of Feed Index (QFI %):-** Quality of feed index (QFI) is the percentage of spacing's that are more than half but not more than 1.5 times the theoretical spacing. This is a measure of how close the spacing's are to the theoretical spacing.

 **Actual Field Capacity (AFC):-** it is the effective field capacity of a machine in the field, expressed in ha/hr.

 **Theoretical Field Capacity (TFC):-** it depends only on the full operating width of the machine and the average travel speed in the field, expressed in ha/hr.

 **Field Efficiency (FE %):-** is the ratio of effective field capacity to theoretical field capacity, expressed in percentage.

2.5.1. Laboratory tests for evaluation of the performance of planter

Laboratory test is used to check the seed placement spacing, seed rate and seed damage. Panning *et al.* (2000) found that seed spacing uniformity in the laboratory was better than or equal to the seed spacing uniformity found in field testing. Differences in seed spacing uniformity were attributed to seed bounce and roll, which occurred in the furrow but not in the laboratory test method.

Finally, skips and multiples are removed from the data, the average spacing can be calculated using the remaining data and the average can be compared to the desired average seed spacing and the CV of the seed spacing's can be calculated

2.5.2. Field tests for evaluation of the performance of planter

Tuber spacing measurements are performed immediately after planting (before germination) and after germination.

2.5.2.1. Field test before germination

Soil is carefully removed from above the tuber and tuber spacing is then measured using a measuring tape. In this case, modifications are made to the machine to enable the furrow to remain open and not covered.

2.5.2.2. Field test after germination

The field testing was conducted to determine the effectiveness and performance of the prototype planter by determining the pattern of distribution of the tuber and the percentage germination of the tuber after planting. The depth of seed placement was measured by removing the plant from soil. The plant population was assessed by counting the number of plants per unit area.

3. MATERIALS AND METHODS

3.1. Experimental Site

The automatic tractor mounted potato planter prototype has been developed in, Menschen für Menschen Foundation (Agro-Technical and Technology College) at Harar Town. The performance evaluation was carried out at Haramaya University main campus; geographically it is located between 9°22'03" N and 9°27'12" N latitude and between 41°05'26" E and 41°58'14" E longitude. Its altitude is 1950.00 m above sea level. The mean annual rainfall of the location is 760.00 mm (Belay *et al.*, 1998). The mean maximum and minimum annual temperatures are of 23.40°C and 8.25°C, respectively. The site has a bimodal rainfall distribution and is representative of a sub-humid, mid-altitude agro-climatic zone.

The soil type of the experimental site is a well-drained deep alluvial with a sub-soil stratified with loam and sandy loam (Tamire, 1973). The soil has organic carbon content of 1.15%, total nitrogen content of 0.11%, available phosphorus content of 18.2 mg kg soil⁻¹, exchangeable potassium content of 0.65 cmolc kg soil⁻¹ (255 mg kg soil⁻¹), pH of 8.0, and percent sand, silt, and clay contents of 63, 20, and 17, respectively (Simret, 2010).

3.2. Experimental Planting Material Used

The experimental potato tuber was of Badhasa cultivar; since, it was one of the potential potato cultivars in the Haramaya district. In Haramaya areas, the released cultivar Badhasa produced significantly higher number of total and marketable tubers over the other cultivars. The varieties were developed by potato improvement programme of Haramaya University and are recommended for mid and high altitude areas of Eastern and Western Hararghe.

3.3. Mechanical Design Considerations

The design of tractor mounted potato planter and modifications were done based on agronomic practices, mechanical and ergonomic requirements. The mechanical design requirements related to power source, traction, soil property, tuber metering mechanism and physical

properties of tuber were considered. Similarly, the ergonomics design requirements were also considered. The selection of materials has been done using standards based on force, stress analysis made for each members of the machine, and the stress generated will not exceed a permissible limit for the material used. In addition, hitching points design and manufacturing was also done by using the standards for 30 hp mini tractor.

3.4. Physical Properties Potato Tuber

Physical properties of potato tuber involved in the study were investigated to optimize the design of the planter's components. The physical properties of potato tuber such as length, width, thickness, weight, volume, bulk density, sphericity, repose angle, arithmetic and geometric mean diameters, surface area, were measured or calculated. One hundred (100) tubers from the representative samples were used to make measurements using digital caliper with the accuracy 0.01 mm. The geometric mean diameter (d_g) of planting material was determined using the Eqn. (4) (Mohsenin, 1986).

$$d_g = \sqrt[3]{a \times b \times c} \quad 4$$

where: - d_g = geometric mean diameter, mm
 a = major diameter of potato tuber, mm
 b = intermediate of potato tuber, mm
 c = minor diameter of the potato tuber, mm

The sphericity of the tubers was determined using the Eqn. (5) (Richard, 1998).

$$S = \frac{d_g}{a} \times 100\% \quad 5$$

where: - S = sphericity, %

The steepest angle of descent relative to the horizontal plane to which a potato tuber can be piled without slumping was determined using open-ended cylinder filled with 10.00 kg potato

tubers. The cylinder was placed on a horizontal surface and lifted gently. Then the vertical height (h) and horizontal spread of tubers (d) at the bottom of the heap as shown in the Figure 1 were measured and the angle of repose calculated using Eqn. (6) (Fowler and Wyatt, 1960).

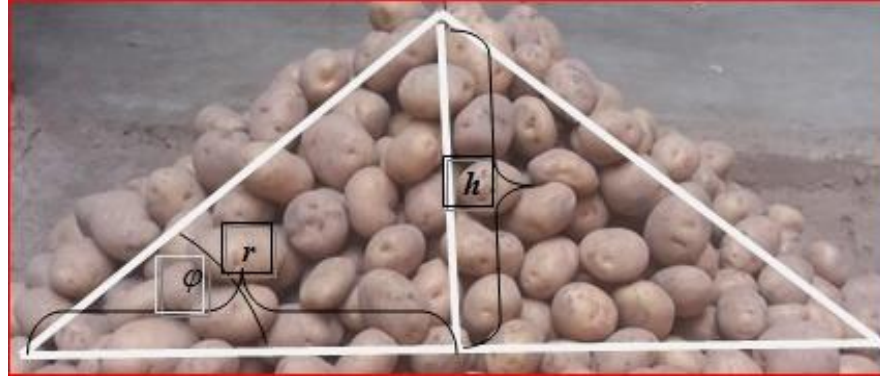


Figure 1: Determination of the repose angle of potato tuber

$$\tan \varphi = \frac{h}{r} \Rightarrow \varphi = \tan^{-1} \left(\frac{h}{r} \right)$$

6

where: - φ = inclination angle at which potato tuber start to slide down, degree
 h = height of cone, cm
 r = radius of cone, cm

To ensure free flow of tubers, the slope of the hopper bottoms were made to have angles or inclination with respect to the horizontal slightly greater than the average repose angle of the tubers.

3.4.1. Determination of bulk density of potato tuber

The Bulk density of potato tubers was determined using the mass-volume relationship. Tubers filled into an empty plastic container of pre-determined volume and weighed; the bulk density was determined by dividing the weight of the samples by the container volume (Fraser *et al.*, 1978, Ghabel *et al.*, 2010). The bulk density of potato tuber was determined using Eqn. (7) (Mohsenin, 1986).

$$\rho_b = \frac{M_t}{V_c}$$

7

where: - ρ_b = bulk density, kg/m³
 M_t = mass of tubers, kg
 V_c = container volume, m³

3.5. Design of Prototype Potato Planter

The prototype of potato planter was tractor mounted type, automatic planter. The tractor mounted potato planter prototype was manufactured in Menschen für Menschen Foundation (Agro-Technology College) at Harar Town. It has frame, hopper, metering device, furrow opener, tuber guide, power transmission means and covering device as main component parts. The prototype potato planter is shown in Figure 2.

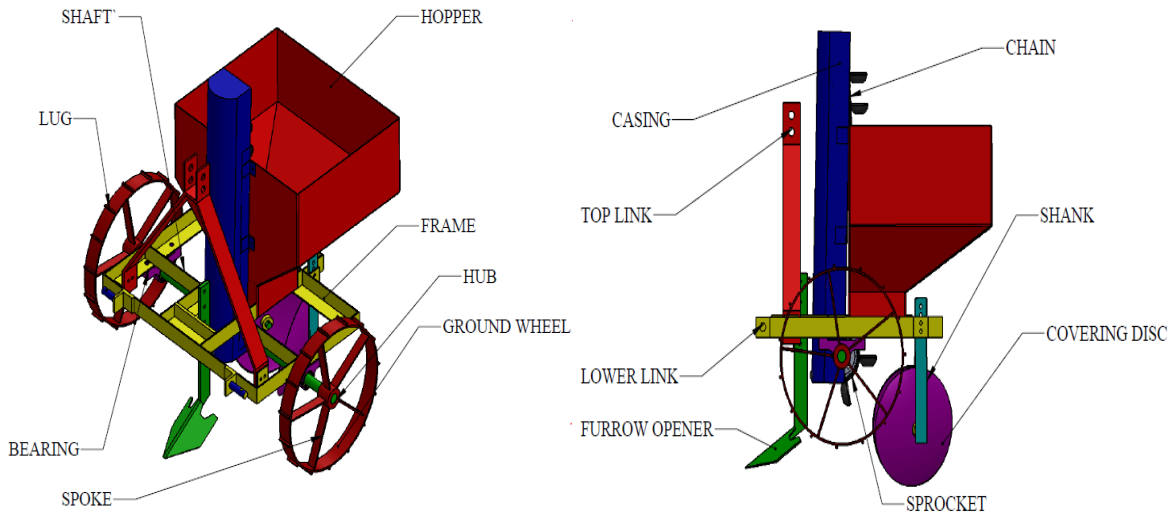


Figure 2: Isometric and side view of a prototype planter

3.5.1. Design of the hopper

The angle of repose of potato seed was 37°, therefore the slope angle of the bottom surface was kept as 42°.

3.5.1.1. Theoretical volume of the hopper

The total volume of hopper was calculated using Eqn. (8) see Figure 3.

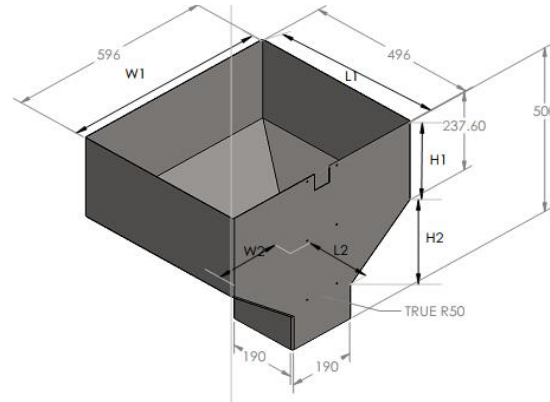


Figure 3: Isometric view of the hopper, all units are in mm

Theoretical volume was calculated by using simple mathematical equations; from Figure 3.

$$V_{Th} = \frac{((L_1 \times W_1 \times H_1) + \frac{1}{3} (A_1 + A_2 + \sqrt{A_1 \times A_2}) \times H_2)}{2} \quad 8$$

where:-

V_{TH} = theoretical volume of hopper, m^3

A_1 = area of top base, ($A_1 = L_1 \times W_1 = 100 \text{ cm} \times 60 \text{ cm} = 6000 \text{ cm}^2$)

A_2 = area of bottom base, ($A_2 = L_2 \times W_2 = 40 \text{ cm} \times 20 \text{ cm} = 800 \text{ cm}^2$)

H_1 = height of rectangle, 24 cm

L_1 = top length of top base, 100 cm

W_1 = top width of top base, 60 cm

H_2 = height of truncated pyramid, 16 cm

L_2 = length of bottom base, 40 cm

W_2 = width of bottom base, 20 cm

The calculated volume found to be 0.096 m^3 .

3.5.1.2. Actual volume of the hopper based on seeding rate

The actual volume of the hopper was estimated using the Eqn. (9, 10 and 11);

$$P_p = \frac{10,000m^2}{R_s \times P_s} \quad 9$$

where: - P_p = plant population per hectare, tuber/hectare

P_s = plant spacing, 30.00 cm = 0.30 m

R_s = row spacing, 75.00 cm = 0.75 m

$$P_p = \frac{10,000m^2}{R_s \times P_s} = \frac{10,000m^2}{0.75m \times 0.3m} = \underline{\underline{44,444tubers/ hectare}}$$

The net volume of hopper must be able to hold the seed at full load, and the seed rate was estimated using Eqn. (10) (Itsi, 2011).

$$SR = P_p \times W_t \quad 10$$

where: - W_t = average weight of potato tuber, 51.35 gram/tuber

S_R = seed rate, kg/ha

$$SR = P_p \times W_t = 44,444tubers/ha \times 51.35 \frac{gram}{tuber} \cong \underline{\underline{2282.2kg/ha}}$$

$$V_a = \frac{SR}{n\rho_b} \quad 11$$

where: - V_a = actual volume of hopper, m³

S_R = seed rate, 2282.2 kg/ha

n = number of refilling per hectare, (Assumed, $n = 66$)

$$\rho_d = \text{bulk density of potato tuber, } \rho_d = 590 \frac{\text{kg}}{\text{m}^3}$$

$$V_a = \frac{2282.2 \frac{\text{kg}}{\text{ha}}}{66 \frac{\text{refillings}}{\text{ha}} \times 590 \frac{\text{kg}}{\text{m}^3}} = \underline{\underline{0.0586 \text{m}^3}}$$

Actual volume of hopper was less than the theoretical volume of hopper; therefore, the design was safe. A 34.00 kg potato tuber was used while additional 2.00 kg potato tubers were used as buffer stock; therefore, the capacity of the hopper was 36.00 kg at full level.

3.5.1.3. Weight of hopper and casing

To determine the weight of hopper, volume of hopper material was estimated first as shown in Figure 4. The hopper material was made from 2.00mm thick mild steel sheet metal. Volume of hopper can also be calculated by using Eqn. (12 and 13) was used to calculate the weight of hopper.

$$V_h = A_h \times t \tag{12}$$

where:- A_h = surface area of the hopper, m^2
 t = thickness of the hopper material, m

$$W_h = V_h \times \rho \times g \tag{13}$$

where: - W_h = weight of the hopper material, N
 V_h = volume of the hopper material, m^3
 ρ = density of hopper material (for mild steel $\rho = 7850 \text{ kg/m}^3$)
 g = acceleration due to gravity, 9.81 m/s^2

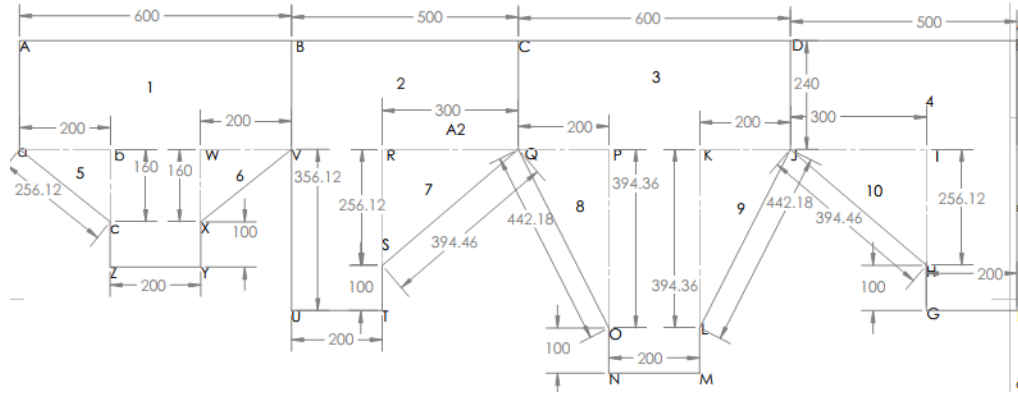


Figure 4: Surface developmental view of hopper

Accordingly,

i. **Total area of the hopper A_h can be determined as;**

$$A_h = ((AB \times BV + bW \times WY) + (BC \times CQ + VR \times RT) + (CD \times DJ + PK \times KM) + (DE \times DJ + IG \times GF)) \\ + \frac{1}{2} (ab \times bc + WV \times WX + RQ \times RS + QP \times PO + KL \times KJ + JI \times IH))$$

$$A_h = \underline{\underline{1.01m^2}}$$

ii. **Volume of hopper material, V_h ;**

$$V_h = A_h \times t$$

where: - t = thickness of hopper material, $t = 2mm = 0.002m$

$$V_h = A_h \times t = 1.01m^2 \times 0.002m = \underline{\underline{0.002m^3}}$$

iii. **Mass of hopper becomes, M_h ;**

$$m = V_h \times \rho = 0.002m^3 \times 7850 \frac{kg}{m^3} = \underline{\underline{15.86kg}}$$

Total mass of hopper was calculated to be 20.52 kg including the weight of casing.

3.5.2. Design of frame

The two design factors considered in the determination of the material required for the frame were weight and strength. In this design, the frame as shown in Figure 5 was fabricated from

mild steel angle iron of 50.00 mm x 50.00 mm x 4.00 mm that gives the required strength and rigidity.

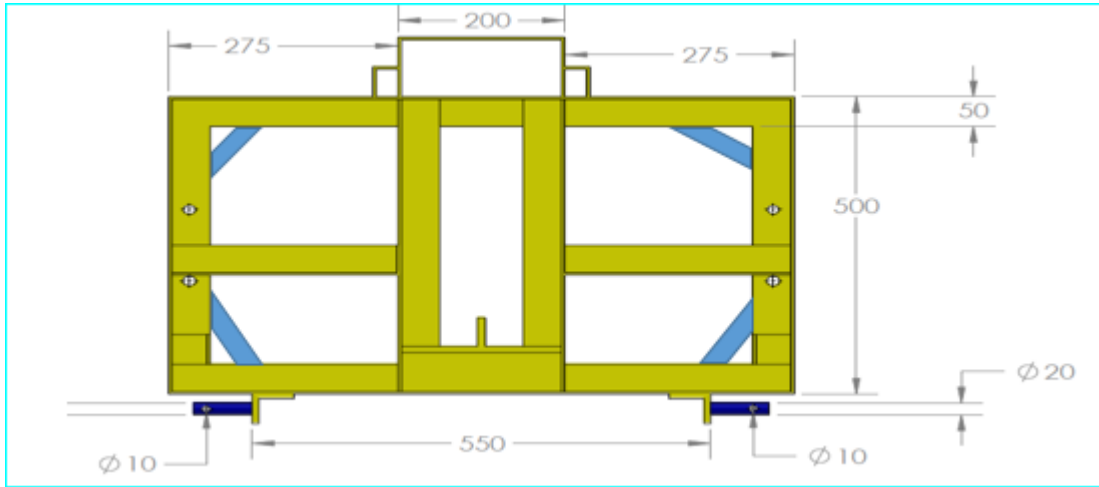


Figure 5: Top view of the main frame

The weight of the frame was estimated from the volume of angle iron used and its density and found out to be 13.32 kg.

3.5.3. Design of furrow opener and shank

The furrow opener was designed and manufactured in such way that it has a provision to alter depth of furrow. Siemen *et al.*, (1965) suggested that a rake angle 30° be used for planter furrow openers though Similarly, Darmora and Pandey (1995) reported that lower draft was observed with furrow openers having smaller width and a rake angle of 40° or less. The average soil force acting on the furrow opener was calculated using Eqn. (14) (Sharma, 2010).

$$F_f = w \times d \times k_o$$

14

where:-

F_f = average soil force acting on the furrow opener, N

w = width of furrow, 10.00 cm

d = depth of furrow, 12.50 cm

k_o = specific soil resistance = 0.20 kg/cm^2 (Dubey, 2003)

The horizontal soil resistance is assumed to be three to five times higher than specific resistance (Atul and Satyendra, 2011). In this design, the horizontal soil force was calculated as follows assuming that it will be three times greater than the nominal value.

$$F_f = w \times d \times k_o = 10\text{cm} \times 12.5\text{cm} \times 5.88 \frac{\text{N}}{\text{cm}^2} = \underline{\underline{735\text{N}}}$$

The force acting on the furrow opener was obtained by using the Eqn. (15) where the factor of safety is 3.

$$F_o = 3 \times F_f \quad 15$$

$$F_o = 3 \times F_f = 3 \times 735\text{N} = \underline{\underline{2205\text{N}}}$$

This force was acting at the one third of sweep height from its tip. The tine can be considered as a cantilever as shown in the Figure 6, so the maximum bending moment for a cantilever with a length of 40.00 cm using Eqn. (16) (Kurtz *et al.*, 1984).

$$M_b = F_o (H_1 + (h_o - a)) \quad 16$$

where: - M_b = Bending moment, Nmm

F_o = horizontal soil resistance, $F_o = 2205\text{ N}$

$H_1 = 30\text{ cm} = 300\text{ mm}$ as shown in the (Figure 6)

h_o = height of inclined sweep, $10\text{ cm} = 100\text{ mm}$

$a = h_o/3 = 100.00\text{ mm}/3 = 33.33\text{ mm}$

Thus,

$$M_b = F_o (H_1 + (h_o - a))$$

$$M_b = 2250\text{ N} \times (300\text{ mm} + (100\text{ mm} - 33.33\text{ mm})) = 825007.50\text{ Nmm}$$

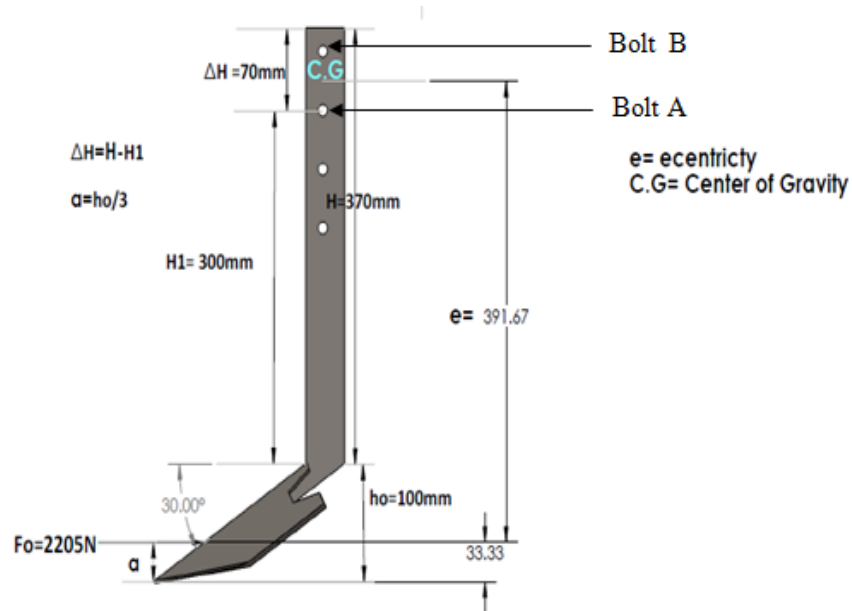


Figure 6: Right Side view of a furrow opener

3.5.3.1. Determination of width and thickness of the shank

The most assumed ratio of thickness to width of tine is 1:3 to 4 (Atul and Satyendra, 2011). For this design the thickness (t) to width (b) was taken as 1:4 which means $b = 4t$. The width and thickness of the shank was calculated by using the bending stress (normal stress) using Eqn. (17) (Atul and Satyendra, 2011).

$$\sigma_b = \frac{6M_b}{t \times b^2} \quad 17$$

where: - t = thickness of shank, (Assumed, $t = b/4$)

b = width of shank, $b = 4t$

σ_b = allowable bending stress (165 N/mm^2 , www.fao.org.)

$$\text{Thus, } \sigma_b = \frac{6M_b}{t \times b^2} = \frac{6M_b}{t \times (4t)^2} = \frac{6M_b}{16t^3}$$

$$t^3 = \frac{6M_b}{16 \times \sigma_b} = \frac{6 \times 8085735 \text{ Nmm}}{16 \times 165 \text{ N/mm}^2} = 1837.67 \text{ mm}^3$$

$$t = \sqrt[3]{1837.67 \text{ mm}^3} = \underline{\underline{12 \text{ mm}}}$$

Therefore, the width of shank becomes, $b = 4 \times t = 4 \times 12 \text{ mm} = \underline{\underline{48.00 \text{ mm}}}$

3.5.3.2. Shear stress on the shank of furrow opener

Torsional shear stress acting on the shank when turning the openers inside the soil at headland was determined using Eqn. (18) (Atul and Satyendra, 2011).

$$\tau = \frac{9F_o \times W_w}{8b \times t^2} \quad 18$$

where,

τ = shear stress, N/mm²

F_o = soil resistance acting horizontally, ($F_o = 2205 \text{ N}$)

W_w = width of furrow opener, ($W_w = 100 \text{ mm}$)

t = thickness of shank, ($t = 12 \text{ mm}$)

b = width of shank, ($b = 48 \text{ mm}$)

$$\text{Thus, } \tau = \frac{9F_o \times W_w}{8b \times t^2} = \frac{9 \times 2205 \text{ N} \times 100 \text{ mm}}{8 \times 48 \text{ mm} \times (12 \text{ mm})^2} = 38 \text{ N/mm}^2 = \underline{\underline{36 \text{ MPa}}}$$

Therefore the design was safe, since allowable shear stress of mild steel was 115 MPa (www.fao.org).

3.5.3.3. Determination of the diameter of bolt

The recommended planting depth could be attained by repositioning the adjustable furrow opener on the frame. The total load taken by each bolt was calculated in three steps. In the first

step the shear force (F_o) is divided equally among the bolts and the primary shear (F') can be determined by using the following Equ. (19) (Budynas, 2006);

$$F' = F_o / n \quad 19$$

where: - F_o = shear force, $F_o = 2205.00 \text{ N}$
 n = refers to the number of bolts, $n = 2$ bolts
 F' = direct load, or primary shear, N

Thus, $F'_A = F'_B = F_o/n = (2205\text{N})/2 = 1102.50 \text{ N}$ this force is equally distributed to each bolt therefore, the average primary shear force, $F'_o = 1102.5 \text{ N}$

In the second step, the moment load, or secondary shear (F'') was determined using the Eqn. (20) which is the additional load on each bolt due to eccentric loading. The force taken by each bolt depends upon its radial distance from the centroid (Budynas, 2006).

$$F_A'' = \frac{F_o \times e \times r_A}{r_A^2 + r_B^2} \quad 20$$

where: - F''_A = secondary shear, N
 e = eccentric distance from force applied to the center of gravity ($e = 391.67 \text{ mm}$)
 r_A = radial distance of bolt A, from the center of gravity ($r_A = 25 \text{ mm}$)
 r_B = radial distance of bolt B, from the center of gravity ($r_B = 25 \text{ mm}$)

i. **For bolt A**, see Figure 6;

$$F_A'' = \frac{F_o \times e \times r_A}{r_A^2 + r_B^2} = \frac{2205\text{N} \times 391.67\text{mm} \times 25\text{mm}}{(25\text{mm})^2 + (25\text{mm})^2} = \underline{\underline{1727265\text{N}}}$$

ii. **For bolt B**, see Figure 6;

$$F_B'' = \frac{F_O \times e \times r_B}{r_A^2 + r_B^2} = \frac{2205N \times 391.67mm \times 25mm}{(25mm)^2 + (25mm)^2} = \underline{\underline{1727265N}}$$

Since, the secondary shear force acting on the bolt was equal, therefore the average secondary shear force becomes, $F'' = 17272.65 \text{ N}$.

In the third step, the resultant force acting on each bolt can be determined by using the following Equation (21) (Budynas, 2006);

$$F_R = F' + F'' \quad 21$$

where:- F_R = resultant force acting on the bolt, N

θ = since the angle between the two forces ($\theta = 0^\circ$)

$$F_R = 11025N + 1727265N = \underline{\underline{1837515N}}$$

The resultant force acting on the bolt (A) was maximum hence; it would be subjected high stress. By using the Eqn. (22 & 23) a diameter of bolt would be determined (Budynas, 2006);

$$\tau_{\max} = \frac{F_R}{A_b} = \frac{\sigma_{yt}}{2 f.s} \quad 22$$

where: σ_{yt} = yield point stress in tension, for steel bolt from, $\sigma_{yt} = 330 \text{ N/mm}^2$

d_b = diameter of bolt, mm

A_b = area of bolt, mm^2

$f.s$ = factor of safety (assumed to be $f.s = 2$)

$$A_b = \frac{F_R \times 2 \times f.s}{\sigma_{yt}} = \frac{1837515N \times 2 \times 2}{330 \text{ N/mm}^2} = \underline{\underline{222.73 \text{ mm}^2}}$$

$$A_b = \frac{\pi d_b^2}{4} \quad 23$$

$$d_b = \sqrt{\frac{4 \times A_b}{\pi}} = \sqrt{\frac{4 \times 222.73 \text{ mm}^2}{3.14}} = \underline{\underline{16 \text{ mm}}}$$

A bolt with maximum diameter of 16 mm was used to faster furrow opener with the frame.

3.5.3.4. Weight of the furrow opener

The weight of the furrow opener was calculated from it volume and density. It was found out to be 3.05 kg.

3.5.4. Design of covering device

The covering device assembly included two revolving concave discs, axle and shank. The discs revolving on the short axle and the shank were bolted on the frame. The discs were manufactured from 3.00 mm thick mild steel sheet metal by forging. The diameter of covering and ridging discs (D_d) was calculated using Eqn. (24) (Sharma, 2010).

$$D_d = \frac{k \times d_p}{\cos \beta} \quad 24$$

where, D_d = disc diameter, cm
 k = dimensionless coefficient, $k = 2.5$ was taken (Sharma, 2010)
 d_p = depth of plow, 10 cm
 β = tilt angle (15° to 25°), 25° of tilt angle was selected

$$D_d = \frac{k \times d_p}{\cos \beta} = \frac{2.5 \times 10 \text{ cm}}{\cos 25^\circ} = 27.58 \cong \underline{\underline{30 \text{ cm}}}$$

The radius of curvature of the disc (R) was calculated using Eqn. (25) (Sharma, 2010). The parameters are shown in the Figure 7.

$$R = \frac{D_d}{2\sin\phi}$$

25

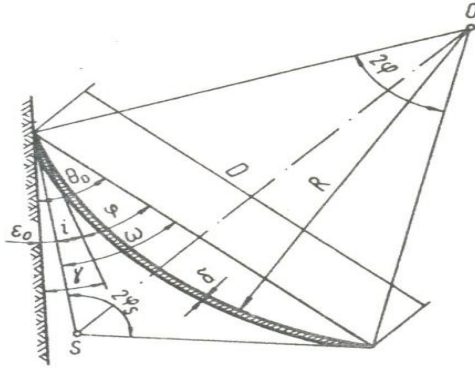


Figure 7: Radius of curvature of a disc

where:

D_d = disc diameter, 300 mm

ϕ = half of center angle of the arc formed by the cutting disc,

$\phi = \alpha - \varepsilon - i$ (Sharma,2010)

α = disc angle in the direction of travel, $\alpha = 45^\circ$

ε = back cleaning angle, 3-5°, 5° was taken

i = sharpness/taper angle of disc 15-25°, 25° was taken

$\phi = 45 - 5 - 25 = 15^\circ$

$$R = \frac{D_d}{2\sin\phi} = \frac{300\text{mm}}{2\sin 15^\circ} = \underline{\underline{580\text{mm}}}$$

The outer diameter (D) and length (L) of hub of disc covering device were designed using Eqn. (26 and 27) (Khurmi and Gupta, 2005). The design of concave disc was shown in the Figure 8.

$$D = 2 \times d$$

26

where:- D = outside diameter of hub, mm
 d = diameter of axle, mm
 $D = 2 \times d = 2 \times 20\text{mm} = \underline{\underline{40\text{mm}}}$

$$L = 1.5 \times d$$

27

where: - d = diameter of axle, mm
 L = Length of hub, mm

$$L = 1.5d = 1.5 \times 20\text{mm} = \underline{\underline{30\text{mm}}}$$

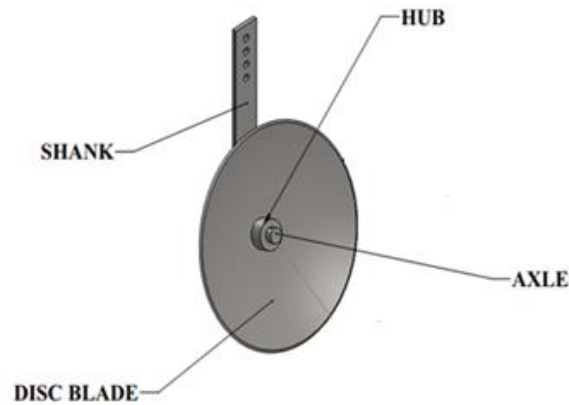


Figure 8: Isometric view of covering device

Draft required to pull two concave discs in the soil was calculated using Eqn. (28) (Sharma, 2010).

$$F_d = n(w_c \times d_p \times k_o \times f.s) \quad 28$$

where, w_c = width of cut, ($w_c = D_d/3 = 30 \text{ cm}/3 = 10 \text{ cm}$)
 d_p = depth of plow, 10 cm
 k_o = specific soil resistance ($k_o = 0.20 \text{ kg/cm}^2$)

F_d = soil force acting on the disc required, N

n = number of discs, 2

$f.s$ = factor of safety, 3

$$F_d = n(w_c \times d_p \times k_o \times f.s) = 2(10cm \times 10cm \times 5.88 \frac{N}{cm^2} \times 3) = \underline{\underline{3528N}}$$

The soil force acting disc was, $F_d = 1764$ N, the total mass of covering device comprises the masses of shanks, axles, hubs and concave discs, and estimated to be 5.03 kg.

3.5.5. Design of three- point hitch

From the total weight of planting machine, only 25 % of the weight is taken by tractor hydraulic system and the remaining 75% is carried by planter ground wheel during working condition (Sharma, 2010).

The designing of three-point hitching was made based on (ASAE Standard S217.10). The hitching bars were made of flat bar 60 mm x 6 mm thick mild steel , the lower link pins have a diameter of 19 mm and the top link has a pin hole of 22 mm as shown in the isometric view Figure 9;

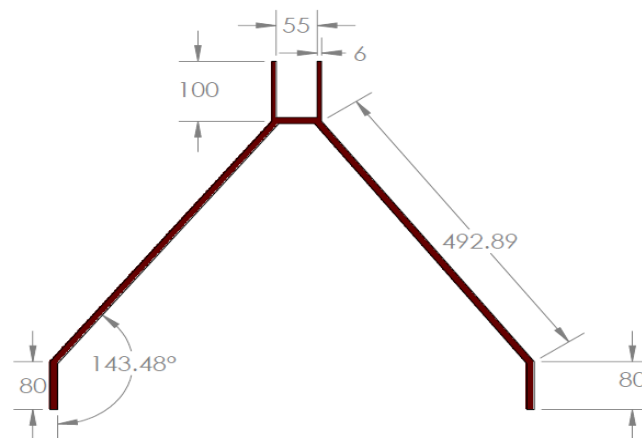


Figure 9: Three-point hitch

$$\begin{aligned}
A_{bars} &= L_{total} \times W_{bar} \\
A_{bars} &= \underline{84900mm^2} \\
V_{bar} &= A_{bar} \times t = 509400mm^3 = \underline{0.00051m^3} \\
m_{bar} &= \rho \times V_{bar} = 7850 \frac{kg}{m^3} \times 0.00051m^3 = \underline{4kg}
\end{aligned}$$

The total mass of three point hitch was found to be; 4 kg.

3.5.6. Design of ground wheel

The planter's ground wheel is located in two ends of the shaft. The rim of wheel was manufactured from mild steel flat iron 60mm x 5mm. To withstand the loads from the weight of planter and to get acceptable soil sinkage; a diameter of 430.00 mm ground wheels were used. The diameter was selected mainly based on planter height.

The width of wheel depends on type of soil and wheel sinkage. The ground wheel was lugged on its periphery, in order to get positive rotation under the muddy field conditions. Each wheel had five spokes made from mild steel flat bar 30 mm x 5 mm thick and welded between the rim and hub at 72° intervals as shown in the Figure 10.

The hub serves as a radial support to the center bushing and braces the wheels circular circumference. The thickness of rim (T) was calculated by following relationship Equ. (29) (Pandya and Shah 1962).

$$T = \frac{D_w}{200} + 3.175 \quad 29$$

where:- T = thickness of the rim, mm
 D_w = diameter of ground wheel, mm

$$T = \frac{D_w}{200} + 3.175 = \frac{430mm}{200} + 3.175mm \cong 5mm .$$

3.5.6.1. Design of ground wheel hub

The hub of a wheel is one of the most important components of rigid wheel. It gives support to the spokes and the axle. The diameter and length of hub were calculated by using Equ. (30 and 31) (Khurmi and Gupta, 2005).

$$D = 2 \times d \quad 30$$

where: - D = outside diameter of hub, mm

d = diameter of shaft, 30 mm

L = length of hub, mm

$$D = 2 \times d = 2 \times 30\text{mm} = \underline{\underline{60\text{mm}}}$$

$$L = 1.5 \times d \quad 31$$

$$L = 1.5 \times d = 1.5 \times 30 = \underline{\underline{50\text{mm}}}$$

3.5.6.2. Design of spokes

The number of spokes was calculated by using the Equ. (32) developed by (Khurmi and Gupta, 2005).

$$n = 2.10 \sqrt{\frac{D_w}{100}} \quad 32$$

where:- n = number of spokes

D_w = diameter of wheel, 430 mm

$$n = 2.10 \sqrt{\frac{D_w}{100}} = 2.10 \sqrt{\frac{430}{100}} = 4.35 \cong \underline{\underline{5\text{pokes}}}$$

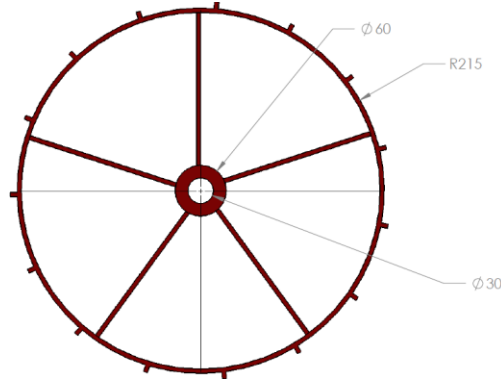


Figure 10: Right side view of ground wheel

3.6. Mass of Prototype Planter

In order to estimate the stresses on each component parts of planter and to select proper shaft diameter for the prototype planter, the total weight were estimated using appropriate equations. The total weight of planter comprised; the weights of hopper, frame, metering device, furrow opener, furrow covering devices, three-point hitch and the weights of potato tuber in the hopper and estimated to be 85.93 kg (843 N).

3.7. Determination of the Total Draft Required to Propel Planter

The total draft requirement was calculated using Eqn. (33).

$$F_D = 2F_{RR} + F_o + F_d \quad 33$$

where:- F_D = total horizontal draft force, N

F_{RR} = rolling resistance force, N

F_o = horizontal soil force acting on the furrow opener, N

F_d = horizontal soil force acting on the covering devices, N

3.7.1. Rolling Resistance

The coefficient of rolling resistance (μ), was estimated using Eqn. (34) (Reece, 2002).

$$\mu = \left(\left(\frac{Z}{D_w} \right)^{0.5} + i \right) \quad 34$$

The rolling resistance force, F_{RR} , was calculated by using Equ. (35) as shown below;

$$F_{RR} = \left(\left(\frac{Z}{D_w} \right)^{0.5} + i \right) \times M_w \quad 35$$

where:-

μ = coefficient of resistance

D_w = Diameter of wheel, 430.00 mm

Z = Maximum wheel sinkage (, $Z = 0.05 \times D_w = 0.05 \times 430 \text{ mm} = 22 \text{ mm}$)

M_w = Weight of the planter on each wheel, $(0.75 \times 843 \text{ N})/2 = 316.13 \text{ N}$

i = gradient of the field, (Assumed, $i = 5\%$)

$$F_{RR} = \left(\left(\frac{Z}{D_w} \right)^{0.5} + i \right) \times M_w = \left(\left(\frac{22\text{mm}}{430\text{mm}} \right)^{0.5} + 0.05 \right) \times 316.13\text{N} = \underline{\underline{87.31\text{N}}}$$

3.7.2. Torque produced on the ground wheel

Torque produced by ground wheel was determined using Eqn. (36), (Reece, 2002).

$$T = F_{RR} \times r \quad 36$$

where:- T = torque produced on the ground wheel, Nm
 F_{RR} = rolling resistance force, 87.13 N
 r = radius of ground wheel, 430 mm/2= 215 mm=0.215 m
 $T = F_{RR} \times r = 87.13N \times 0.215m = \underline{\underline{18.73Nm}}$

3.7.2.1. Shear strength of the ground wheel

Thomas and Brown, (2005) analyzed shear strength (τ) of ground wheel considering the wheel as thin-walled vessels as shown in Figure 11. The maximum torque produced in the ground wheel was calculated using Eqn. (37).

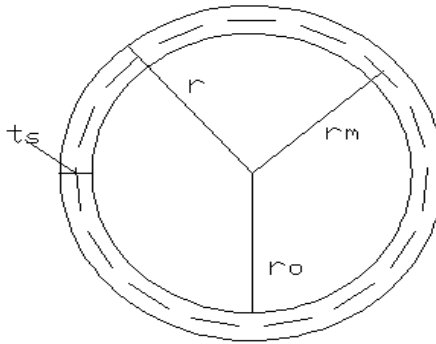


Figure 11: Sectional view of ground wheel

$$T_{\max} = 2 \times \tau_{\max} \times \pi \times r_m^2 \times t_s \quad 37$$

where:- $\tau_{\max}$ = maximum shear stress,) ($\tau_{\max} = 207MPa$) (www.fao.org.)
 $T_{\max}$ = maximum torque, Nmm
 r_m = the mean radius of the wheel,
 $r_m = r - t_s/2 = 215 \text{ mm} - 5 \text{ mm}/2 = 212.50 \text{ mm}$
 t_s = the thickness of the wheel rim, 5 mm

$$T_{\max} = 2 \times \tau_{\max} \times \pi \times r_m^2 \times t_s = 2 \times 207 \frac{N}{mm^2} \times 3.14 \times (212.5mm)^2 \times 5mm = \underline{\underline{293.5kNm}}$$

Comparing this value with the actual torque produced by the wheel tells us, the wheel is safe from failure. The angle of twist produced by the applied torque was calculated using Eqn. (38), (Thomas and Brown, 2005).

$$\theta = \frac{T \times r_m \times w}{4 \times G \times (\pi \times r_m)^2 \times t_s} \quad 38$$

where: - θ = the angle of twist, degree

w = width of the wheel, 60 mm

T= torque produced by the wheel, 18730 N mm

L_m = median line of length of wheel, (L_m = 667.25 mm)

G = modulus of rigidity of steel, 78 GPa (www.fao.org.)

$$\theta = \frac{T \times L_m \times w}{4 \times G \times (\pi \times r_m)^2 \times t_s} = \frac{18730 \text{ Nmm} \times 667.25 \text{ mm} \times 60 \text{ mm}}{4 \times 78000 \text{ N/mm}^2 \times (3.14 \times (212.5 \text{ mm})^2)^2 \times 5 \text{ mm}}$$

$$\theta = \underline{\underline{2.4 \times 10^{-8} \text{ radians}}}$$

$$\theta = 2.4 \times 10^{-8} \text{ radians} \times \frac{180^0}{\pi} = \underline{\underline{0.0000013}}$$

3.8. Design of Metering Device

A roller chain was selected for transmitting power from ground wheel to metering mechanism. The recommended 30 cm intra row planting space was adopted as recommended by EARO (2004). Chain-cup metering mechanism was designed. In this design, maximum diameter of potato tuber 55.00 mm was considered and the internal diameter of cup was 1.2 times the maximum major diameter of potato tuber (55.00 mm); i.e. 66.00 mm.

3.8.1. Chain drive for metering mechanism

This type metering mechanism consists of; vertically rotated chain conveyor, the driving sprocket (larger sprocket) and driven (small sprocket). The driving sprocket was coupled with the shaft via keyway and it has identical rotation with ground wheel. Therefore, revolution per minute (rpm) of driving sprocket (larger sprocket, N_1) was equal to the revolution per minute (rpm) of the ground wheel, (N_w) in this regard ($N_1 = N_w = 56$ rpm). The velocity ratio assumed for this design was ($VR = 1/2$).

The number of teeth on the smaller sprocket plays an important role in deciding the performance of a chain drive. A small number of teeth tend to make the drive noisy. A large number of teeth make chain pitch smaller, which is favorable for keeping the drive silent, and reducing shock. Accordingly, the number of teeth at the driving sprocket ($T_1 = 38$) was selected based on assumed velocity ratio of ($VR = 1/2$). Therefore, the number of teeth for the driven sprocket was determined using Eqn. (39), (Khurmi and Gupta, 2005).

$$V.R = \frac{N_1}{N_2} \quad 39$$

where:- N_1 = revolution of driving sprocket, 56 rpm
 N_2 =revolution of driven sprocket, rpm

$$V.R = \frac{N_1}{N_2} \Rightarrow N_2 = \frac{N_1}{V.R} = \frac{56}{0.5} = \underline{\underline{115rpm}}$$

Number of teeth on the driven sprocket was calculated by using Equation (40) (Khurmi and Gupta, 2005)

$$T_2 = \frac{T_1 \times N_1}{N_2} \quad 40$$

where:- T_1 = number of teeth of driving sprocket, 38
 T_2 = number of teeth of driven sprocket,

$$T_2 = \frac{T_1 \times N_1}{N_2} = \frac{38 \times 56 \text{ r.p.m}}{112 \text{ r.p.m}} = \underline{\underline{19}}$$

For the teeth number of driving sprocket ($T_1 = 38$) a pitch circle diameter was taken $P_1 = 115.35\text{mm}$ (ANSI ISO 2403, 1991 Duplex chain-Type B).

3.8.2. Maximum power available to the metering device

The power transmission was provided from ground wheel through sprockets and chain for seed metering. Therefore, selecting appropriate chain type for the metering mechanism was depended on the design power and rpm of the driving sprocket.

Assumptions made,

 Operating speed of tractor, $V = 4.8 \text{ km/hr} = 1.33 \text{ m/s}$

The power transmitted to metering device was calculated by using Eqn. (41) (Ryder, 1989).

$$P = \frac{2 \times \pi \times N_w \times T}{60}$$

41

where:- P = Power transmitted, W
 N_w = rpm of ground wheel, assuming 5% wheel slip

$$N_w = \frac{V \times 60}{\pi \times D} (1 - s) = \frac{1.33 \frac{\text{m}}{\text{s}} \times 60}{3.14 \times 0.43 \text{ m}} (1 - 0.05) = \underline{\underline{56 \text{ rpm}}}$$

T = Torque on the ground wheel, 18.73 Nm

$$P = \frac{2 \times \pi \times N_w \times T}{60} = \frac{2 \times 3.14 \times 56 \text{ rpm} \times 18.73 \text{ Nm}}{60} = \underline{\underline{110 \text{ W}}}$$

The design power was calculated using Eqn. (42) (Khurma and Gupta, 2005)

$$P_d = P \times K_s \quad 42$$

where:- P = rated power, 110 W

P_d = design power, W

K_s = service factor (K_s = K₁ x K₂ x K₃ = 1.25 x 1.5 x 1 = 1.88)

$$P_d = P \times K_s = 110 \text{ W} \times 1.88 = \underline{\underline{206.8 \text{ W}}}$$

Based on the design power (206.8 W) and for 56 rpm the driving sprocket, 06B-type chain was selected and that has a pitch of 9.525 mm (ANSI ISO 2403, 1991). Velocity of the chain was determined by using Equ. (43) (Khurmi and Gupta, 2005);

$$V_c = \frac{\pi \times D_p \times N_1}{60} \quad 43$$

where, V_c = chain velocity, m/s

D_p = Pitch circle diameter of the driving sprocket, 115.35 mm

N₁ = rpm of ground wheel, N₁ = N_w = 56 rpm

$$V_c = \frac{\pi \times D_p \times N_1}{60} = \frac{3.14 \times 0.11535 \text{ m} \times 56 \text{ rpm}}{60} = \underline{\underline{0.32 \text{ m/s}}}$$

3.8.2.1. Determination of the total load on the driving side of the chain

The total load (or total tension) on the driving side of the chain is the sum of the tangential driving force (F_t), centrifugal tension in the chain (F_c), the tension in the chain due to sagging (F_s) can be calculated by using Eqn.(44, 45 and 46) (Khurmi and Gupta, 2005).

i. Tangential force, F_t

$$F_t = \frac{P}{V_c} \quad 44$$

where:- P = Power transmitted to the sprocket, $P = 110 \text{ W}$

V_c = Velocity of chain, 0.32 m/s

$$F_t = \frac{P}{V_c} = \frac{110\text{W}}{0.32\text{m/s}} = \underline{\underline{343.75\text{N}}}$$

ii. Centrifugal force, F_c

$$F_c = m \times V_c^2 \quad 45$$

where:- m = mass per length of chain, $m = 0.74 \text{ kg/m}$ (ANSI ISO 2403-1991, duplex- Type B)

$$F_c = m \times V_c^2 = 0.74 \frac{\text{kg}}{\text{m}} \times (0.32 \frac{\text{m}}{\text{s}})^2 = \underline{\underline{0.076\text{N}}}$$

iii. Sagging force, F_s

$$F_s = k \times m \times g \times C \quad 46$$

where:- g = gravitational acceleration, 9.81 m/s^2

$k = 1$, for vertical chain position

C = chain center to center distance, 0.66 m

$$F_s = k \times m \times g \times C$$

$$F_s = 0.74 \text{ kg/m} \times 9.81 \text{ m/s}^2 \times 0.66 \text{ m}$$

$$F_s = \underline{\underline{4.80 \text{ N}}}$$

Therefore, the total load on the driving side of the chain can be calculated using Eqn. (47);

$$F_T = F_t + F_c + F_s \quad 47$$

$$F_T = F_t + F_c + F_s = 343.75\text{N} + 0.076\text{N} + 4.8\text{N} = \underline{\underline{348.63\text{N}}}$$

3.8.2.2. The spacing between cups in metering chain

The size and number of cells on the chain depended on the size of tuber and desired planting space. The spacing between cups (S_c) on the chain was determined using Eqn. (48).

$$S_c = \left(\frac{d_1}{D} \right) \times R_s \quad 48$$

where:-

S_c = spacing between cups, mm

d_1 = diameter of driving sprocket, 115.35 mm

D_w = diameter of ground wheel, 430 mm

R_s = intra-row spacing, 300 mm(recommended)

$$S_c = \left(\frac{d_1}{D} \right) \times R_s = \left(\frac{115.35\text{mm}}{430\text{mm}} \right) \times 300\text{mm} = \underline{\underline{7.62\text{cm}}}$$

To attain the recommended intra-row spacing of 30 cm between potato tubers) the cups were placed at interval of 7.62 cm.

3.8.2.3. Determination of the length of chain

Length of chain was calculated using Eqn. (49) (Khurmi and Gupta, 2005)

$$L = \frac{p}{2}(T_1 + T_2) + 2C + \frac{\left[\left(\frac{p}{2} \operatorname{cosec} \left(\frac{180^\circ}{T_1} \right) - \left(\frac{p}{2} \operatorname{cosec} \left(\frac{180^\circ}{T_2} \right) \right) \right]^2}{C}$$
49

where:-
 L = length of chain, m
 T_1 = number of teeth on the driving sprocket, 38
 T_2 = number of teeth on the driven sprocket, 19
 C = centre to center distance between sprockets, (Assumed, 0.66 m)
 p = pitch of the chain, $p = 9.525 \times 10^{-3}$ m

$$L = \frac{p}{2}(T_1 + T_2) + 2C + \frac{\left[\left(\frac{p}{2} \operatorname{cosec} \left(\frac{180^\circ}{T_1} \right) - \left(\frac{p}{2} \operatorname{cosec} \left(\frac{180^\circ}{T_2} \right) \right) \right]^2}{C} = 1.6m$$

3.8.2.4. Number cups on the chain

The number of cups on the seed metering device was obtained using Eqn. (50).

$$N_c = \frac{L}{S_c}$$
50

where:-
 N_c = number of cups on the metering device
 L = length of chain, m
 S_c = spacing between cups, m

$$N_c = \frac{L}{S_c} = \frac{1.6m}{0.0762m} = \underline{\underline{21 \text{ cups}}}$$

Thus, 21 equal cups were attached on the chain at interval of 0.0762 m. Since, recommended potato size for ware production was 25 mm up to 55 mm (Lung'aho *et al.*, 2007), the metering cup has maximum inside diameter of 66.00 mm. The number of potato tubers planted per second was estimated using Eqn. (51) (Buitenwerf *et al.*, 2006). The metering mechanism is shown in Figure 12.

$$f_{pot} = \frac{V_c}{R_s} \quad 51$$

where: - V_c = chain- cup speed, 0.32 m/s
 R_s = recommended planting space, 0.30 m
 f_{pot} = rate of potatoes leaving the duct, tuber/second

$$f_{pot} = \frac{V_c}{R_s} = \frac{0.32 \text{ m/s}}{0.30 \text{ m}} = \underline{\underline{1.06 \text{ tuber/second}}}$$

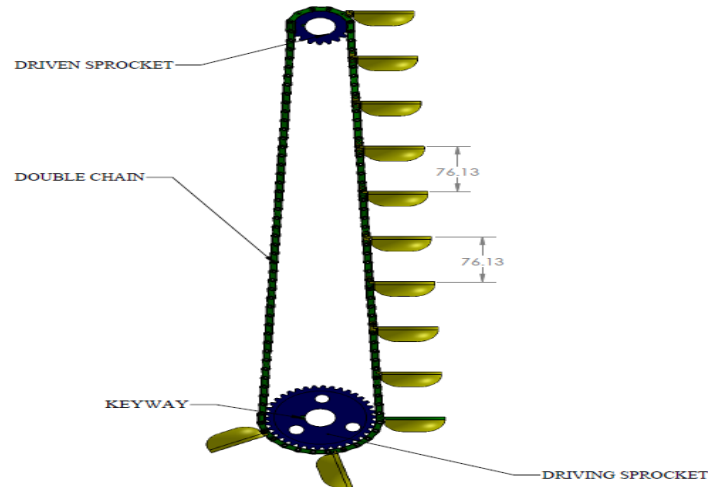


Figure 12: Side view of metering device, in mm

3.8.3. Power required by metering device

The total power required by the metering device during planting operation was calculated using Eqn. (52, 53 and 54) (Renold.n.d.)

$$P_c = F_{VCP} \times V_c \quad 52$$

$$F_{VCP} = 9.81 \left[\left(\frac{m_c \times C}{S} \right) + (m \times C) + \left(\frac{C \times m_t}{S} \right) \right] + D_f \quad 53$$

$$D_f = \frac{90 \times m_t}{S} \quad 54$$

where:-
 P_c = total power required by the metering device, W
 F_{vcp} = vertical chain pull load, N
 V_c = chain velocity, 0.32 m/s
 C = chain center to center distance, (Assumed = 0.66 m)
 m_c = mass of individual cup (Assumed = 0.13 kg)
 m = mass of chain, (m = 0.74 kg/m)
 m_t = mass of tuber on the cup (measured = 0.053 kg)
 S = spacing between cups (calculated = 0.0762 m)
 D_f = dredge factor, N

From the above equations;

$$D_f = \frac{90 \times m_t}{S} = \frac{90 \times 0.05kg}{0.0762m} = \underline{\underline{59N}}$$

$$F_{vcp} = 9.81[(\frac{m_c \times C}{S}) + (m \times C) + (\frac{C \times m_t}{S})] + D_f)$$

$$F_{vcp} = 9.81[(\frac{0.13kg \times 0.66m}{0.0762m}) + (0.74 \frac{kg}{m} \times 0.66m) + (\frac{0.66m \times 0.05kg}{0.0762m})] + 59N)$$

$$F_{vcp} = \underline{79N}$$

Therefore, the total power required by the metering device was;

$$P_c = F_{VCP} \times V_c = 79N \times 0.32m/s = 25.28W$$

This calculated value was much smaller than that of the rated power of chain drive ($P = 110W$). This also indicates that the tangential force exceeds the chain pull load, $F_t > F_{vcp}$, the design was safe.

3.8.4. Determination of total draft force

The total draft force acting on the prototype planter comprises; horizontal rolling resistance force, horizontal soil force acting on the furrow opener and covering devices and vertical chain pull load during planting.

The total horizontal draft force was calculated using the Eqn. (55)

$$F_D = 2F_{RR} + F_o + F_d \quad 55$$

where, F_D = total horizontal force acting on the prototype planter, N

F_{DR} = resultant draft required to pull planter, N

F_{RR} = rolling resistance force, $F_{RR} = 87.31$ N

F_o = horizontal soil force acting on the furrow opener, $F_o = 2205$ N

F_d = horizontal soil force acting on the covering devices, $F_d = 3528$ N

F_{vcp} = vertical chain pull load, $F_{vcp} = 79$ N

$$F_D = 2F_{RR} + F_0 + F_d = (2 \times 87.31N) + 2205N + 3528N = \underline{\underline{5907.62N}}$$

Total resultant draft force required to propel prototype potato planter was found to be 5907.62N.

3.9. Design of the Drive Shaft

The material used for the shaft was mild steel round bar with key way at mid span of it, in order to attain identical rotation of sprocket with ground wheel. The shaft was subjected to bending and twisting moment that induces bending stress and torsional shear stresses.

The locations and magnitudes of the maximum bending moment in the shaft was analyzed both in vertical and horizontal plane YX and ZX-plane respectively as shown in Figure 13.

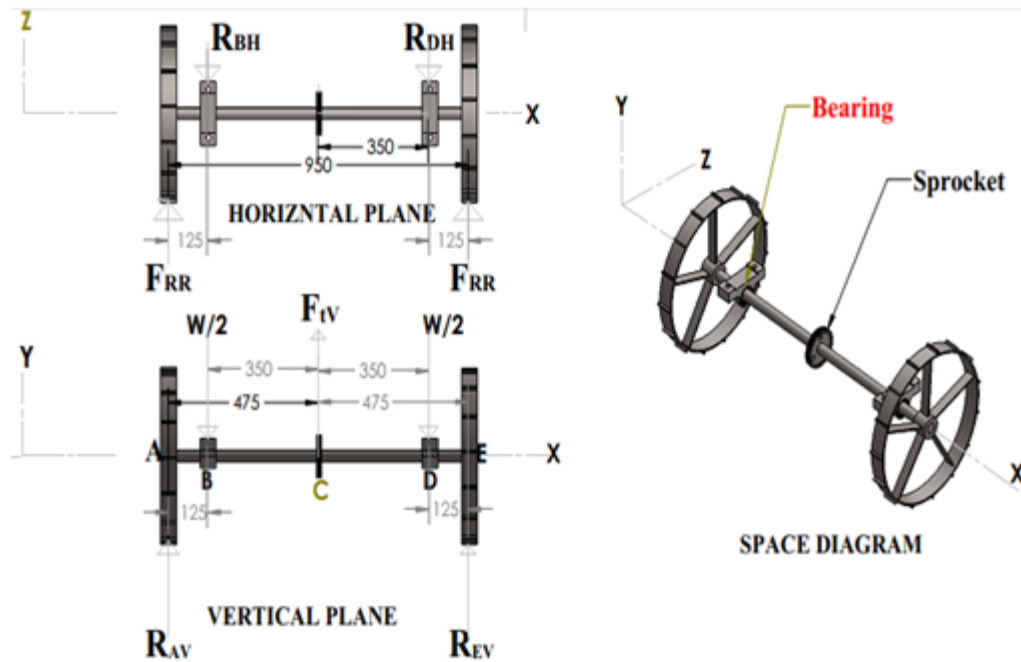


Figure 13: Forces on vertical plane (x, y) and horizontal plane (x, z)

where:- R_{BH} = reaction force at point B (bearing support), in horizontal plane, 94.88 N

R_{DH} = reaction force at point B (bearing support), in horizontal plane, 94.88 N

R_{AV} = reaction force at point A in vertical plane, 141.98 N

R_{EV} = reaction force at point E in vertical plane, 141.98 N

F_{tV} = tangential force in the vertical plane, 348.31 N

F_{RR} = rolling resistance force, 87.31 N

W = weight of a planter, 632.26 N

3.9.1. Bending moment diagram on the vertical plane

From the Figure 14 below, a bending moment on the vertical plane

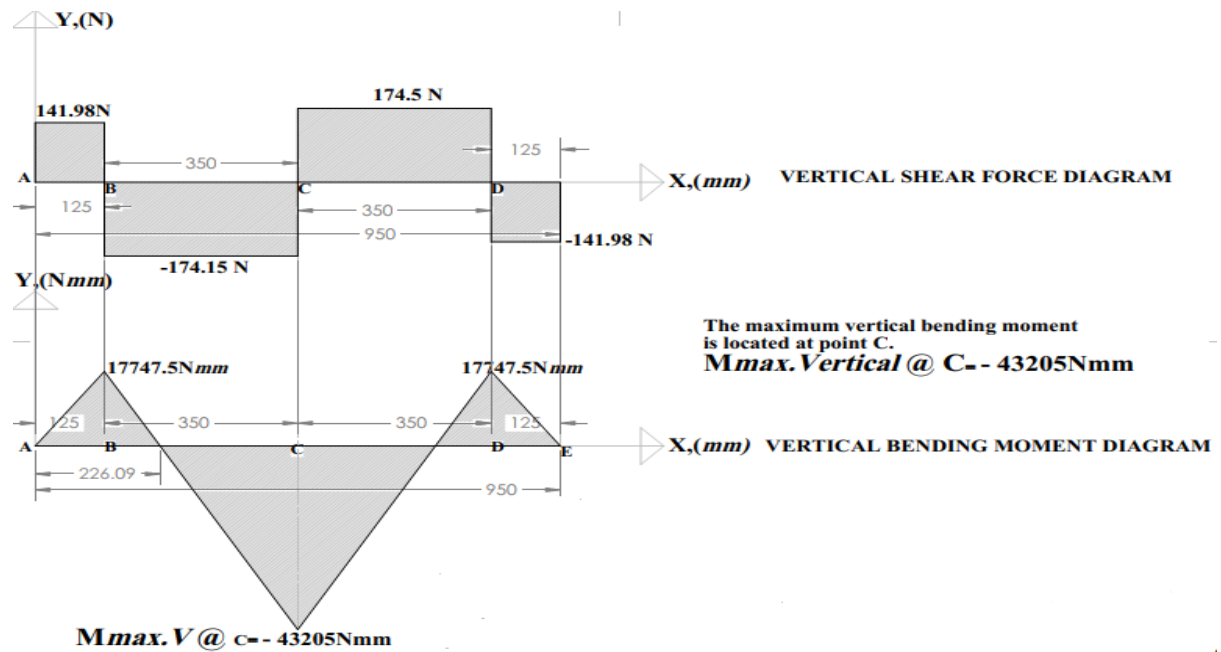


Figure 14: Vertical shear force and bending moment diagram

3.9.2. Bending moment diagram on the horizontal plane

The horizontal shear force and bending moment diagram was shown in the Figure 15;

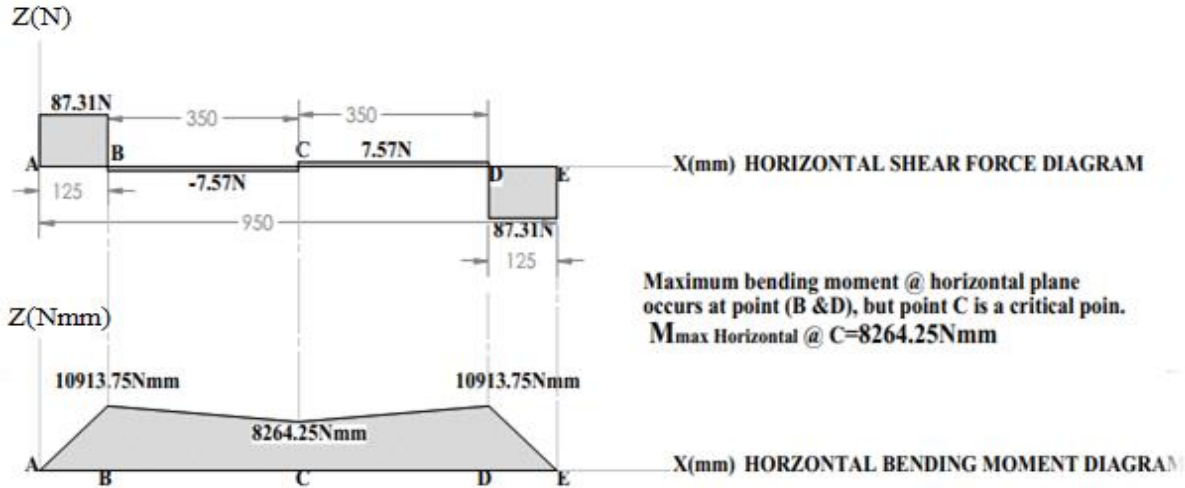


Figure 15: Horizontal shear force and bending moment diagram

From the bending moment diagrams, the maximum bending moments on horizontal and vertical planes were found to be 8264.25Nmm and 43205 Nmm, respectively and the resultant was 43988.30 Nmm.

3.9.3. Determination of the shaft diameter

The shaft was subjected to combined torque and bending moment, therefore, the design of the shaft was made using maximum shear stress theory (Bhandari, 1997). According to ASME (1995) code equation, the bending and torsional moments are to be multiplied by factor (K_b) and (K_t) respectively.

Furthermore, it was noted that for shaft without key way, the allowable stress (τ_{all}) must be 55 MPa and for the shaft with key way the allowable stress (τ_{all}) should not exceed 40MPa. ASME code also suggests that, the allowable design stress (τ_{all}) to be 25% considered for shafts with keyways.

For this design allowable shear stress was assumed to be ($\tau_{all} = 35$ MPa) and by taking 25% for keyway consideration ($\tau_{all} = 0.75 \times 35$ MPa). The diameter of the shaft was obtained using the ASME code given by the Eqn. (56);

$$d^3 = \frac{16}{\pi \tau_{allowable}} \sqrt{(K_b M_{max})^2 + (K_t T_{max})^2} \quad 56$$

where:-
 M_{max} = maximum bending moment, $M_{max} = 43988.3 \text{ Nmm}$
 T_{max} = maximum torsional moment, $T_{max} = 18730 \text{ Nmm}$
 K_b = combined shock applied to bending moment, $K_b = 2$
 K_t = combined shock applied to torsion moment, $K_t = 1.5$
 d = minimum shaft diameter, mm

$\tau_{allowable}$ = allowable shear stress, ($\tau_{allowable} = 0.75 \times 35 \text{ MPa} = 26 \text{ MPa}$)

From the above calculation, a solid shaft with 30 mm diameter had been selected.

3.9.4. Bearing selection

Bearings were selected based on their load carrying capacity, life expectancy and reliability. Ball bearings are fitted into bushing provided at the two ends of the frame support the shaft on which the wheels are attached as shown in Figure 16.

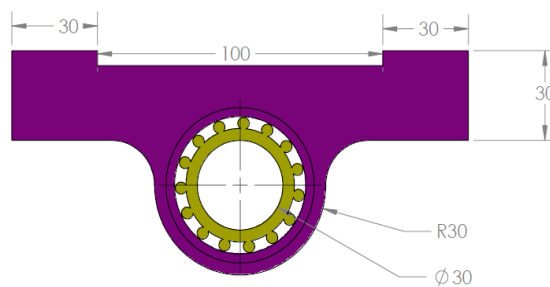


Figure 16: Side view of bearing and plummer block

3.10. Power Requirement to Propel the Potato Planter

The total power required to propel the planter was determined using Eqn.(57) (Khurmi and Gupta, 2005).

$$P_T = F_D \times V$$

57

where: P_T = total power required to propel potato planter, hp
 F_D = resultant draft force, 5907.62 N
 V = forward speed of tractor, 1.33 m/s

$$P_T = F_D \times V = 5907.62 \text{ N} \times 1.33 \text{ m/s} = 7857.13 \text{ W}$$

$$P_T = \frac{7857.13 \text{ W}}{745.7 \text{ W}} \times 1 \text{ hp} = \underline{\underline{10.54 \text{ hp}}}$$

Therefore, total power needed to propel prototype potato planter was found to be 10.54 hp.

3.11. Experimental Design

The experiment was laid out as split-split plot design according to the principle of factorial experiment with three replications as shown in the Table 1 and Table 2. A plot size used was 39 m x 42 m = 1638 m² including spacing between plots and space for tractor turning. The field layout was made accordingly and each treatment was assigned randomly to the experimental units within each block. The experimental area was divided into 3- replications and each replication into three main plots.

Then, randomly assign the main-plot treatments to the main plots, separately and independently. The randomization procedure had three parts;

- Randomly assign main plot treatments to main plots
- Randomly assign subplot treatments to the subplots
- Randomly assign sub-subplot treatments to the sub-subplots

The three different sizes of potato tubers were assigned to main plot, the three levels of forward speed of tractor was assigned to sub plot, whereas the three levels of hopper loading was assigned to sub-sub plot and the experimental design layout is shown in Figure 17. The size of each experimental plot was 3 m x 3 m consisting of five rows, which accommodated 10 plants per row. Plants in the central three rows were used for evaluating performance of prototype potato planter. The total observation had been 4050 potato tubers.

Table 1: Experimental setup

Factor	Independent Variables	Symbol	Levels	Dependent Variable
Main Factor	Size of potato tuber	S ₁	(25-35 mm)	Miss index
		S ₂	(35-45 mm)	Multiple index
		S ₃	(45-55 mm)	Damage index
Sub Factor	Tractor Speed	V ₁	(2.5 km/hr)	Quality of feed index
		V ₂	(3.6 km/hr)	Degree of variation
		V ₃	(4.8 km/hr)	
Sub-Sub Factor	Level of hopper fill	H ₁	(25%)	
		H ₂	(50%)	
		H ₃	(75%)	

Key: S₁ = small size of potato tuber V₁ = low tractor speed H₁ = quarter hopper fill
S₂ = medium size of potato tuber V₂ = medium tractor speed H₂ = half hopper fill
S₃ = large size of potato tuber V₃ = high tractor speed H₃ = three forth hopper fill

Table 2: Treatment details of experiment in split-split plot design

Parameters	Description
Statistical Design	Split-split plot design
Treatment combination	3 x 3 x3x3=81
Plot size	3 m x 3 m
Total length of field	42 m
Total width of the field	39 m
Net area	729 m ²
Potato variety	Badhasa
Inter row spacing	75 cm
Inter plant spacing	30 cm

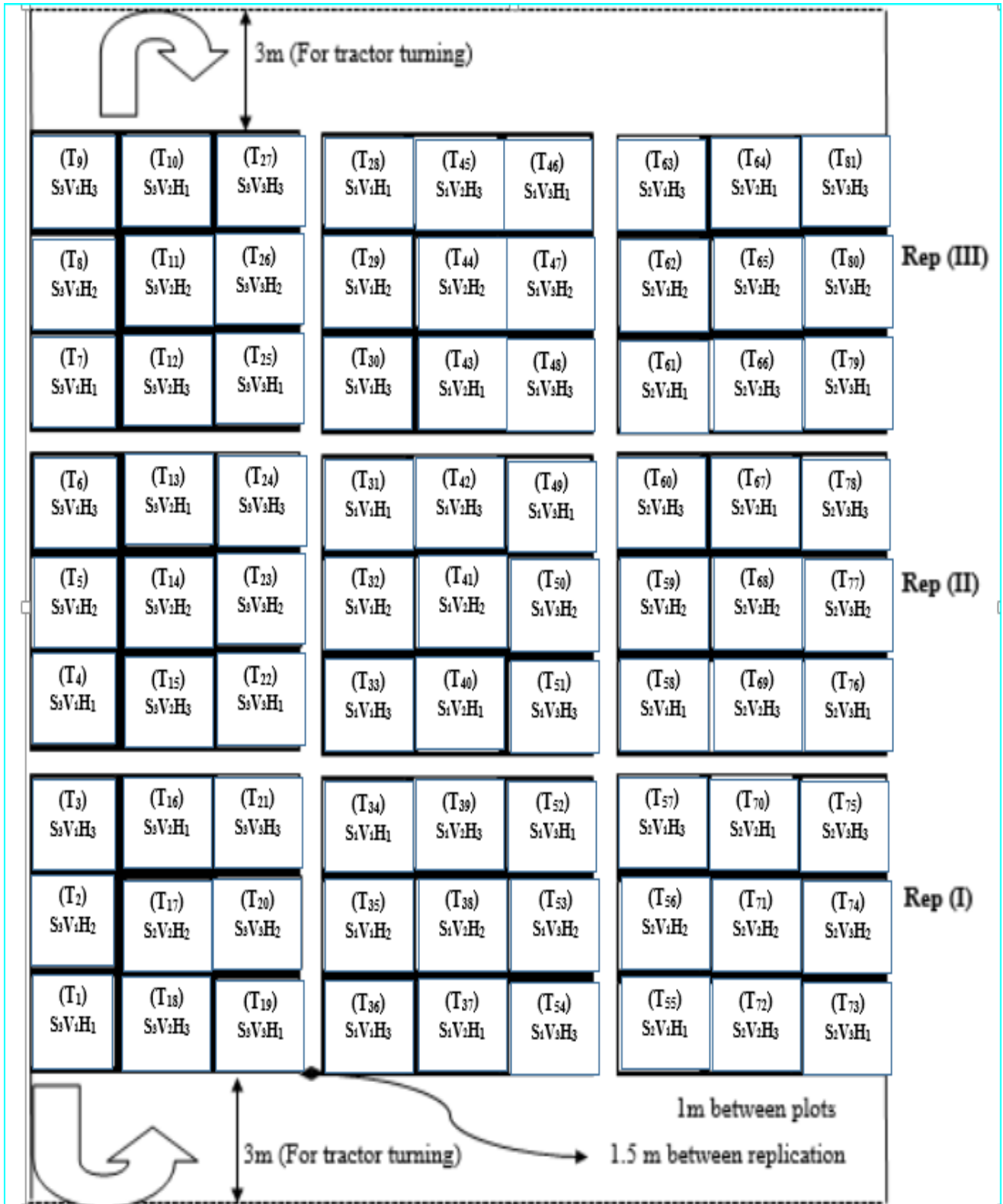


Figure 17: Experimental field layout

3.11.1. Statistical analysis

The data collected were subjected to ANOVA following a procedure appropriate for the design of the experiment (Gomez and Gomez, 1984) and using GenStat 15th edition statistical software. The least significant difference (LSD) test was performed for the mean values of actual seed spacing, seed miss index, seed multiple index, quality of feed index, tuber damage and precision spacing (degree of spacing) in relation to tuber size, operating speed of the tractor and hopper fill level.

The treatment means that were significant difference when F-test at 5% levels of significance; were separated using least significant difference LSD (5%) test. The least significant difference (LSD) test was performed for the mean values of actual tuber spacing, tuber miss index, tuber multiple index and tuber damages in relation to tuber size (sphericity), tractor's forward speed and level of hopper.

3.12. Parameters Measured

3.12.1. Soil penetration resistance

Soil penetration resistance was measured with hand held cone penetrometer. Three random measurements were made in experimental plot.

3.12.2. Soil moisture content

Soil samples were collected randomly for three locations at each test plot from 0 to 15.00 cm depth. The moisture content was determined through oven dry method by keeping known amount of weight in the oven at 105 °C for 24 hours with the help of following relationship. The moisture content (Dry basis) was determined using Eqn. (58) (Rangapara, 2014).

$$M = \frac{W_1 - W_2}{W_2} \times 100\%$$

where:- M = Moisture content (dry base), %
 W₁ = Weight of the wet soil sample, g
 W₂ = Weight of the oven dry sample, g

3.13. Arrangements for Testing of Prototype Potato Planter

Field test was conducted without using covering device order to make desire measurements between tubers. Tuber spacing measurements were performed immediately after planting on a 3m row length of each experimental plots and tuber spacing using measuring tape.

After germination of tuber, the spacing between the plants and the number of plants per area for a known length of ridge was measured to analyze the uniformity of seed spacing. Spacing between adjacent plants was measured in the field after 21 days of planting for plants at 3 m distances along the row. Seed covering device was used during planting time.

The laboratory experiments were conducted to assess the performance in terms of uniformity of tuber spacing and tuber damage during operation, effectiveness of the metering mechanism. The prototype potato planter was run over a level track of moist soil surface of 10.00 m length at recommended speed. A moist soil beneath the tuber outlet prevented bouncing of tubers. The tests were repeated three times and mean was taken. Seed tuber spacing uniformity has been evaluated in terms of;

Percentage external tuber damage was determined using Eqn. (59) (Kachman and Smith, 1995).

$$\text{Tuber damage (\%)} = \frac{N_d}{N} \times 100 \quad 59$$

where: N_d = number of tuber with damage
 N = total number of tuber in the observation

The percentage miss index (MISSI %) was calculated using Eqn. (60) (Kachman and Smith, 1995).

$$MISSI(\%) = \frac{N_1}{N} \times 100 \quad 60$$

where:- N_1 = spacing's that are greater than 1.5 times the theoretical spacing
 N = total number of tuber in the observation

Percent multiple index (MULTI %) was calculated using Eqn. (61) (Kachman and Smith, 1995).

$$MULTI(\%) = \frac{N_2}{N} \times 100 \quad 61$$

where: - N_2 = number of spacing's that are less or equal to half the theoretical spacing

The quality of feed index (QFI %) was calculated using Eqn. (62) (Kachman and Smith, 1995).

$$QFI(\%) = \frac{N_3}{N} \times 100 \quad 62$$

where: - N_3 = Number of spacing between 0.5 times the theoretical spacing and 1.5 times of the theoretical spacing in the given observations

Degree of variation (CV %) values was calculated using Eqn. (59) (Kachman and Smith, 1995).

$$CV(\%) = \frac{SD}{M} \quad 63$$

where: - SD = standard deviation of the observations, cm
 M = mean tuber spacing, cm

A theoretical field capacity was calculated using Eqn. (64) (Kepner *et al.*, 1978).

$$TFC = \frac{W \times S}{10} \quad 64$$

where: - TFC = theoretical field capacity, ha/hr
 S = speed of travel, km/hr
 W = width of the planter, m

The actual or effective field capacity (ha/hr) was calculated using Eqn. (65) (Samuel, n.d.)

$$AFC = \left[\frac{(S \times W \times L \times e)}{((10 \times L) + (D \times S \times W \times L \times e) + (2.778 \times S \times t))} \right] \quad 65$$

where:- AFC = actual field capacity, ha/h
 S = average tractor forward speed, km/h
 W = planter design width, m
 L = average length of the field, m
 e = effective width of the planter, m
 D = is the unproductive time, h/ha
 t = is the time for a turn at row ends, s

The field efficiency calculated using Eqn. (66) (Kepner *et al.*, 1978).

$$FE(\%) = \frac{AFC}{TFC} \times 100 \quad 66$$

Where: TFC = theoretical field capacity, ha/hr
 AFC = actual field capacity, ha/hr

4. RESULTS AND DISCUSSIONS

4.1. Physical Properties of Potato Tuber

A potato tubers of Badhassa cultivar were used as planting material. The physical properties determined including size, geometric mean diameter, bulk density, sphericity and angle of repose were estimated as shown in the Table 3.

The geometric mean diameter of potato tuber for size ranges of 25- 35 mm, 35-45 mm and 45-55 mm were 24.82, 31.62 and 43.11 mm, respectively, whereas the sphericity and bulk density of the tubers for size ranges from 25-35 mm, 35-45 mm and 45-55 mm were 82.28, 80.94, 84.95 and 360, 440 and 590 kg/m³, respectively. The mean angles of repose of the tuber were 37° and 42° used in the design.

Table 3: Physical properties of potato tuber

Physical properties	Sample	Small size	Medium size	Large size
Major diameter	100	30.00 ± 5.00mm	38.50 ± 5.50mm	50.00 ± 5.00mm
Intermediate dia	100	24.00 ± 4.00mm	31.00 ± 7.00mm	41.50 ± 6.50mm
Minor diameter	100	22.00 ± 2.00mm	26.00 ± 4.00mm	37.50 ± 7.50mm
Geometric mean	100	24.82 ± 2.99mm	31.62 ± 4.69mm	43.11 ± 5.68mm
Sphercity	100	82.28 ± 12.08%	80.94 ± 8.52%	84.95 ± 4.78%
Tuber weight	1000	20.28gm	30.46gm	51.35gm
Bulk density	1000	360 kg/m ³	440 kg/m ³	590 kg/m ³
Average repose angle				37°

4.2. Performance Evaluation of the Prototype Potato Planter

During the field test, the moisture content and the bulk density of the soil were 10.5% and 1.36 mg/m³, respectively.

4.2.1. Tuber damage

It was observed that; tuber damage percent was increase every revolution of the feeding system when hopper filled fully and large sized tuber was used. The damage was mainly caused due to friction between metering cups and tubers and impact force during cup unloading and dropping of tuber on to the back of preceding cup.

Visual inspection of tubers indicated that, in some cases, there was visible damage. Percent tuber damage observed during laboratory tests for tuber size ranges from 25-35, 35-45 and 45-55 mm at constant speed was 0.93%, 1.23% and 1.48%, respectively. The highest percent tuber damage was observed with larger tuber size at full hopper level and with high tractor speed of 4.8 km/hr.

4.2.2. Mean tuber spacing

ANOVA (Appendix Table 1) revealed that tuber size, tractor forward speed and hopper fill level had significantly ($p < 0.05$) affected the mean tuber spacing.

The interaction of tuber size and tractor forward speed; tuber size and hopper fill level; and tuber size, tractor forward speed and hopper fill level had significant ($p < 0.05$) on mean effects on tuber spacing. While the interaction of tractor forward speed and hopper fill level had no significant ($p > 0.05$) effect on mean tuber spacing.

As shown in the Table 4, the mean tuber spacing decreased with increasing tuber size and tractor forward speed. The highest tuber spacing of 30.45, 30.31 and 30.16 cm was recorded for tractor forward speed of 4.8 km/hr, tuber size of 45.00-55.00 mm and hopper fill level of 25% respectively.

Whereas, the lowest tuber spacing of 28.21, 28.24 and 28.27 cm was recorded for tractor forward speed of 2.5 km/hr, tuber size of 25.00-35.00 mm and hopper fill level of 75% respectively. Overall, the average mean tuber spacing recorded during field test was 29.20 cm. This recorded planting space is closest to the recommended planting space of 30 cm (EARC, 2004).

4.2.3. The tuber miss index (%)

ANOVA (Appendix Table 3) indicated that tractor forward speed, tuber size, hopper fill level, had significant effect ($p < 0.05$) on tuber miss index.

The interactions of tractor forward speed and tuber size; tractor forward speed and hopper fill level had significant effect ($p < 0.05$) on tuber miss index. Whereas the interactions of tuber size and hopper fill level; and that of tuber size, tractor forward speed and hopper fill level had no significant effects ($p > 0.05$) on tuber miss index.

Table 4 shows the mean comparisons of percent tuber miss index values at three tuber sizes, three tractor forward speeds and three hopper fill levels. While Table 5 shows, the mean comparisons of percent of tuber miss index values the effect of interaction of tuber size and tractor forward speed, and hopper fill level and tractor forward speed on mean percent of tuber miss index.

These results show that there was a significant difference between the mean of three tuber sizes, three tractor forward speeds and three hopper fill levels.

Table 4: The effects of main factors on MISSI (%), MULTI (%), QFI (%) and Mean tuber spacing

Independent Variables	Levels	Dependent variables			
		MISSI (%) ^{av}	MULT (%) ^{av}	QFI (%) ^{av}	Mean Tuber Spacing
Tuber Size	S ₁ (25-35 mm)	4.44 ^c	13.58 ^a	81.98 ^a	28.24
	S ₂ (35-45 mm)	7.90 ^b	9.88 ^b	82.22 ^a	29.04
	S ₃ (45-55 mm)	11.72 ^a	6.54 ^c	81.74 ^a	30.31
LSD (5%)		1.91	1.29	2.63	
Tractor Forward Speed	V ₁ (2.5 km/hr)	4.81 ^c	13.45 ^a	81.73 ^a	28.21
	V ₂ (3.6 km/hr)	7.53 ^b	10.12 ^b	82.35 ^a	28.93
	V ₃ (4.8 km/hr)	11.71 ^a	6.42 ^c	81.87 ^a	30.45
LSD (5%)		1.38	1.11	1.85	
Hopper Fill Level	H ₁ (25%)	10.62 ^a	5.55 ^c	83.83 ^a	30.16
	H ₂ (50%)	8.76 ^b	9.75 ^b	81.48 ^b	29.16
	H ₃ (75%)	4.68 ^c	14.69 ^a	80.63 ^b	28.27
LSD (5%)		1.09	1.12	1.60	

Means followed by the same letter with in the same column are not significantly different at 5% level of significance

Values followed by different letters within each column are statistically different at 5% level of significance

^{av} = average

Table 5: The interaction of two factors on the values of MISSI (%)

Parameter		Source of Variation			Measurement of Mean Difference	
					LSD (5%)	SE($\bar{x}$)
Interaction(V*S)						
		Tuber Size Levels				
		S ₁ (25-35 mm)	S ₂ (35-45 mm)	S ₃ (45-55 mm)		
MISS (%)	Tractor Speed Levels					
	V ₁ (2.5 km/hr)	1.85 ^c	5.18 ^c	7.40 ^c	2.39	1.09
	V ₂ (3.6 km/hr)	5.18 ^b	7.77 ^b	9.63 ^c		
	V ₃ (4.8 km/hr)	6.30 ^b	10.74 ^a	18.11 ^b		
Interaction(V*H)						
		Tractor Speed Levels				
		V ₁ (2.5 km/hr)	V ₂ (3.6 km/hr)	V ₃ (4.8 km/hr)		
MISS (%)	Hopper Fill Level				1.90	0.93
	H ₁ (25%)	6.67 ^a	10.00 ^a	15.18 ^a		
	H ₂ (50%)	5.56 ^a	7.78 ^b	12.96 ^b		
	H ₃ (75%)	2.22 ^b	4.81 ^c	7.00 ^c		

Means followed by the same letter with in the same column are not significantly different at 5% level of significance

Values followed by different letters within each column are statistically different at 5% level of significance

From Table 4 it can be seen that the miss index increases with increasing tractor forward speed and tuber size. Whereas percent of miss index decrease with increase hopper fill level. The highest percent of miss index of 11.72, 11.71 and 10.63% were recorded for tuber size of 45.00-55.00 mm, tractor forward speed of 4.8 km/hr and hopper fill level of 25% respectively.

The increase in miss index due to high tractor speed indicates that when tractor speed increases there was high vibration during operation, therefore, there would be high tendency of tuber drop in to the hopper and the cup skips metering of tuber. It can be seen that, tuber size of 45.00-55.00 mm lead the highest MISSI (%) value of 11.72%.

Similarly, when the size of tuber becomes larger there would be high tendency of tuber skip. When the hopper fill level was 25% , the tuber has long time to stay in the metering cup and due to vibration it would be dropped in to the hopper. The least MISSI (%) was observed with small tuber size 25 mm - 35 mm was found to be 4.44%.

From Table 5 it can be seen that the lowest MISSI (%) was found to be 1.85% for the interaction of tractor speed of 2.5 km/hr and tuber size range of 25-35 mm. While the highest MISSI (%) was found to be 18.11 % for the interaction of tractor speed of 4.80 km/hr and tuber size range of 45-55mm.

In addition, from the Table 5 it can be seen that lower MISSI (%) was found to be 2.22% for the interaction of tractor forward speed of 2.5 km/hr and hopper fill level of 75%. Whereas, higher MISSI (%) of 15.18% was recorded for the interaction of tractor forward speed of 4.8 km/hr and hopper fill level of 25%

Table 6 gives regression equations and from the table it can be seen that MISSI (%) increased with increasing tractor forward speed and decreases with increasing level of hopper fill, since, the coefficient of hopper fill level (H) was negative value. Whereas, the R^2 value of 0.91, 0.83 and 0.87 indicates the independent variables were strongly associated with the percent of miss index.

Table 6: Multiple linear regression equations relating tractor forward speed (V) and hopper fill level (H) to MISSI (%) (Y) over three tuber sizes

Tuber Size	Regression Equation	R ² Value
S ₁ (25 mm-35 mm)	$Y=1.55+1.92V-0.08H$	0.91
S ₂ (35 mm-45 mm)	$Y=5.42+2.43V-0.13H$	0.83
S ₃ (45 mm-55 mm)	$y=2.11+4.70V-0.15H$	0.87

V = Speed of operation (km/hr), H = Hopper fill level (%), S = tuber sizes

4.2.4. The tuber multiple index (%)

ANOVA (Appendix Table 2) revealed that tuber size, tractor forward speed, hopper fill level , the interactions of tuber size and tractor forward speed; and tractor forward speed and hopper fill level had significant effect on ($p < 0.05$) tuber multiple index.

Whereas, the interactions of tuber size and hopper fill level; and tuber size, tractor forward speed and hopper fill level had no significant effect ($p > 0.05$) on seed multiple index.

Table 4 shows the mean comparisons of percent tuber multiple index values at three tuber sizes, three tractor forward speeds and three hopper fill levels.

While Table 7 shows the mean comparisons of percent of tuber multiple index values the effect of interaction of tuber size and tractor forward speed; and hopper fill level and tractor forward speed on mean percent of tuber multiple index. These results show that there was a significant difference between the mean of the interactions of two factors.

Table 7: The interaction of two factors on the values of MULTI (%)

Parameter	Source of Variation				Measurement of Mean Difference	
					LSD (5%)	SE($\bar{x}$)
MULTI (%)	Interactions					
	Tuber Size Levels					
	Interaction(S*V)					
	Tractor Speed Levels	S ₁ (25-35 mm)	S ₂ (35-45 mm)	S ₃ (45-55 mm)		
	V ₁ (2.5 km/hr)	18.52 ^a	13.70 ^a	8.52 ^a	1.12	0.88
	V ₂ (3.6 km/hr)	12.96 ^b	10.00 ^b	6.67 ^b		
	V ₃ (4.8 km/hr)	8.88 ^c	6.66 ^c	4.07 ^c		
	Tractor Speed Levels					
	Hopper Fill Level	V ₁ (2.5 km/hr)	V ₂ (3.6 km/hr)	V ₃ (4.8 km/hr)	1.94	0.95
	H ₁ (25%)	8.52 ^c	5.18 ^c	2.96 ^c		
	H ₂ (50%)	12.96 ^b	9.63 ^b	6.66 ^b		
	H ₃ (75%)	18.89 ^a	15.56 ^a	9.63 ^a		

Means followed by the same letter with in the same column are not significantly different at 5% level of significance
Values followed by different letters within each column are statistically different at 5% level of significance

From Table 4 it can be seen that the multiple index decreased with increasing tractor forward speed and tuber size. Whereas percent of multiple index increased with increase hopper fill level.

The highest percent of multiple index of 14.69, 13.58 and 13.45 % were recorded for hopper fill level of 75%, tuber size of 25.00-35.00 mm and tractor forward speed of 2.5 km/hr respectively.

The lowest percent of multiple index recorded were 5.55, 6.42 and 6.54% with hopper fill level of 25%, tractor forward speed of 4.8 km/hr and tuber size of 45.00-55.00 mm respectively.

It can be seen that, hopper fill level of 75% lead the highest MULTI (%) value of 14.69%. The increase in multiple index due to hopper fill level indicates that due to the hopper filled full there would be high tendency of metering cup to pick more than one tuber.

The leading least MULTI (%) was observed with hopper fill level of 25% was found to be 5.55%. Similarly, when the size of tuber becomes smaller there would be high tendency of tuber doubling with in the metering cup.

From Table 7 it can be seen that the lowest MULTI (%) was found to be 4.07% for the interaction of tractor speed of 4.8 km/hr and tuber size range of 45-55 mm. While the highest MULTI (%) was found to be 18.89 % for the interaction of tractor speed of 2.5 km/hr and hopper fill level of 75%

Results of regression analysis Table 8 the equations shows that tractor forward speed has negative effect on MULTI (%). Which indicates that when tractor forward speed increased the percent of tuber multiple index becomes decreased. Similarly, hopper fill level and percent of tuber multiple index has direct relationship which indicates when hopper fill level increased; the percent of tuber multiple index becomes increased.

Whereas, the R^2 value of 0.93, 0.96 and 0.99 indicates the independent variables were strongly associated with the percent of multiple index.

Table 8: Multiple linear regression equations relating tractor forward speed (V) and hopper fill level(H) to MULTI (%) (Y) over three tuber sizes

Tuber Size	Regression Equation	R ² Value
S ₁ (25 mm-35 mm)	Y=18.25-4.35V+0.22H	0.93
S ₂ (35 mm-45 mm)	Y=10.57-2.74V+0.19H	0.96
S ₃ (45 mm-55 mm)	Y=7.11-2.09V+0.14H	0.99

V = Speed of operation (km/hr), H = Hopper fill level (%)

4.2.5. The quality of feed index (%)

ANOVA(Appendix Table 4) revealed that hopper fill level, the interaction of tuber size and forward speed; the interaction of tuber size and hopper fill level; and the interaction of forward speed and hopper fill level had significant effect ($p < 0.05$) on tuber quality of feed index.

While, tuber sizes, tractor forward speed and the interaction of tuber size, tractor speed and hopper fill level had not any significant effect ($p > 0.05$) on percent quality of feed index.

Table 4 shows the effects of the tuber size, forward speed and level of hopper fill on percent feed index and whereas the combined effect of tuber size and tractor forward speed, tractor forward speed and hopper fill level, and tuber size and hopper fill on percent of tuber quality of feed index was given in the Table 9.

Table 9: The interaction of two factors on the values of QFI (%)

Parameter	Source of Variation			Measurement of Mean Difference	
				LSD (5%)	SE($\bar{x}$)
QFI (%)	Interactions				
	Interaction(S*V)	Tuber Size Levels			
	Tractor Speed Levels	S ₁ (25-35 mm)	S ₂ (35-45 mm)	S ₃ (45-55 mm)	
	V ₁ (2.5 km/hr)	79.67 ^a	81.85 ^a	83.70 ^a	3.20
	V ₂ (3.6 km/hr)	81.11 ^a	82.22 ^a	83.70 ^a	
	V ₃ (4.8 km/hr)	85.18 ^b	83.33 ^a	77.77 ^b	
	Interaction(V*H)	Tractor Speed Levels			
	Hopper Fill Level	V ₁ (2.5 km/hr)	V ₂ (3.6 km/hr)	V ₃ (4.8 km/hr)	
	H ₁ (25%)	84.81 ^a	84.81 ^a	81.85 ^a	2.77
	H ₂ (50%)	81.48 ^b	82.59 ^a	81.11 ^a	
	H ₃ (75%)	78.89 ^b	79.62 ^b	83.33 ^a	
	Interaction(S*H)	Tuber Size Levels			
	Hopper Fill Level	S ₁ (25-35 mm)	S ₂ (35-45 mm)	S ₃ (45-55 mm)	
	H ₁ (25%)	85.56 ^a	84.07 ^a	81.85 ^a	2.77
	H ₂ (50%)	81.85 ^b	82.22 ^a	81.11 ^a	
H ₃ (75%)	78.51 ^c	81.11 ^a	82.22 ^a		

Means followed by the same letter with in the same column are not significantly different at 5% level of significance

Values followed by different letters within each column are statistically different at 5% level of significance

From Table 4 it can be seen that the maximum QFI(%) of 83.83% was recorded for hopper fill level of 25%, whereas, the minimum QFI(%) of 80.63% was recorded for hopper fill level of 75%. This indicates that when hopper fill level increased the QFI(%) decreased.

From Table 9 the maximum quality tuber feed index recorded for the interactions of tuber size range of (25.00-35.00 mm) and hopper fill level of (25%) ; and tuber size range of (25.00-35.00 mm) and tractor forward speed of 4.8 km/hr were 85.56% and 85.18% respectively.

Whereas, the lowest percent of quality of tuber feed index recorded for the interactions of tuber size range of (45.00-55.00 mm) and tractor forward speed of 4.8 km/hr were 77.77% and 78.81% respectively.

Results of regression analysis, made to establish relationships between percent tuber quality of feed index and forward speeds and hopper fill levels are given Table 10. It was observed that the coefficients of hopper fill levels (H) are negative for tuber sizes 25.00-35mm and 35.00-45.00mm which indicates that percent of quality of feed index expected to be decrease with increasing hopper fill.

Whereas, the R^2 value of 0.74, 0.48 and 0.63 indicates the independent variables were intermediately associated with the percent of miss index.

Table 10: Multiple linear regression equations relating tractor forward speed(V) and hopper fill level(H) to QFI (%) (Y) over three tuber sizes

Tuber Size	Regression Equation	R^2 Value
S ₁ (25 mm-35 mm)	Y=80.18+2.43V-0.14H	0.74
S ₂ (35 mm-45 mm)	Y=83.078+0.65V-0.06H	0.48
S ₃ (45 mm-55 mm)	Y=90.85-2.61V+0.01H	0.63

V = Speed of operation (km/hr), H = Hopper fill level (%)

4.2.6. Field capacity and field efficiency determination

The highest theoretical field capacity was 0.34 ha/hr obtained at 4.8 km/hr forward speed while the lowest value of theoretical field capacity was reported to be 0.18 ha/hr at 2.5 km/hr. Field efficiency is the ration of actual field capacity to the effective filed capacity. From the Table 11 maximum efficiency of prototype observed was 72.22% for 2.5 km/hr and the minimum value recorded was 56% for 4.8 km/hr of tractor forward speed.

Table 11: Field capacity and field efficiency determination

Tractor forward speed,km/hr	Actual field capacity,ha/hr	Theoretical field capacity, ha/hr	Efficiency, %
2.5	0.13	0.18	72.22
3.6	0.16	0.25	64
4.8	0.19	0.34	56

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

A prototype potato tuber planter was designed, manufactured, tested for evaluation. Physical properties of potato seeds involved in the study were investigated to optimize the design of the planter's components.

The effect of varying tuber sizes, tractor forward speed and hopper fill level were evaluated in terms of mean tuber spacing (M), the coefficient of variation (CV%), the multiple index (MULTI%), the miss index (MISI%) and the quality of feed index (QFI, %). In addition, field effective field capacity (EFC) and field efficiency (FE %) were assessed.

Experimental potato tuber used for this study was a local Badhassa cultivar. The sphericity of potato tuber size of small category (25.00-35.00 mm), medium category (35.00-45.00 mm) and large category (45.00-55.00 mm) were 82.28%, 80.94% and 84.95%, respectively, indicating that all tubers had more or less spherical shape. For this design, the drive shaft directly controls the tuber metering mechanism which is attached with sprockets and chain system.

Percent mechanical damage on tubers was evaluated using the three different sizes of potato tubers were found to be 0.93%, 1.23% and 1.48%, respectively. The mean tuber spacing recorded during field test was 29.20 cm while the design value was 30.00 cm.

Tractor forward speed had significant ($P < 0.05$) effect on percent miss index. The effect varied with size of potato tubers. The percentage of tuber miss index was increased with increasing tuber size and tractor forward speed, whereas decreased with increasing hopper fill levels.

In general, increase in operational speed tended to increase percent miss index when planting small, medium, and large sized potato tubers using the prototype planter. The highest percent tuber miss indices of 6.3, 10.74, and 18.11% were recorded with small, medium, and large sized potato tubers, respectively, at the planter forward speed of 4.8 km/hr, whereas the lowest

percent tuber miss indexes of 1.85, 5.18 and 7.40% were obtained for small, medium, and large sized potato tubers, respectively, at the planter speed of 2.5 km/hr.

Hopper fill level had significant ($P < 0.05$) effect on percent tuber multiple indices. The effect varied with forward speeds. The highest percent tuber multiple indexes of 18.88, 15.55, and 9.63% were recorded with low, medium, and high speed of tractor, respectively, at the hopper fill level of 75%, the lowest percent tuber multiple indices of 8.52, 5.18 and 2.96% were obtained for low, medium, and high speed of tractor, respectively, at the hopper fill level of 25%.

Hopper fill level had significant ($P < 0.05$) effect on percent quality of feed index. The effect was varied with tuber sizes. The highest percent of quality of feed indexes of 85.56, 84.07 and 81.85% were recorded with small, medium, and large sized potato tubers, respectively, for the hopper fill level of 25%.

Whereas the lowest percent quality of feed indices of 78.51, 81.11 and 82.22% were obtained for small, medium, and large sized potato tubers, respectively, at the hopper fill level of 75%.

5.2. Conclusions

Results of ANOVA revealed that the mean planting space recorded was 29.20cm; this value is close to the recommended planting space of 30cm. Thus, the prototype planter performed the intended function of planting potato tuber at required row to row and plant to plant spacing satisfactory. From the analysis, it can be concluded that the tuber spacing uniformity decrease with varying tuber size, tractor forward speed and hopper fill.

The results obtained from the field tests showed that the planter functioned properly and effectively metered single tuber with minimum damage and had planting capacity of 0.19ha/hr. The highest actual field capacity was found to be 0.19ha/hr at 4.8km/hr.

The average mean tuber spacing was varied with different tuber sizes, tractor forward speed and hopper fill level. However, in this study a tuber size of 35 mm - 45 mm, forward speed of 3.6 km/hr and hopper fill level of 50% gave optimum planting space of 29.04 cm, 28.93 cm and 29.16 cm respectively.

5.3. Recommendations

All the observed values were laid within the recommended levels, hence, this planter was found to be effectively plants potato tuber with recommended row to row and plant space. From the results of this study, a forward speed of 3.6 km/h, tuber size of 35-45 mm and hopper fill level of (50%) could be recommended for the chain-cup potato planter.

Nonetheless, the following issue must be addressed to make the planter popular, adaptable and usable among the farmers.

- This machine is single row planter effort must be made to make multi-row planter
- Graded tuber should be used to meet high efficiency and uniformity in spacing

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7. APPENDIX

7.1. Appendix Tables

Appendix Table 1: The effect of tuber size, tractor forward speed, hopper fill level and their combination on mean tuber spacing

Source of Variation	Degree of	Sum of	Mean	Computed	Tabular F-Value	
	Freedom	Squares	Square	F-Value	5%	1%
Main Plot Analysis						
Replication (r)	2	0.24	0.12			
Tuber Size(S)	2	58.85	29.43	121.87**	6.94	18.00
Error(s)	4	0.96	0.24			
Subplot Analysis						
Tractor Forward Speed(V)	2	70.77	35.39	208.60**	3.89	6.93
Interaction (S X V)	4	6.65	1.66	9.80**	3.26	5.41
Error(v)	12	2.03	0.16			
Sub-subplot Analysis						
Hopper Fill Level(H)	2	48.01	24.00	125.14**	3.26	5.25
Interaction(S X H)	4	3.69	0.92	4.80**	2.63	3.89
Interaction (V X H)	4	-154.51	-38.63	<0 ^{ns}	2.63	3.89
Interaction (S X V X H)	8	168.19	21.02	109.60**	2.21	3.05
Error(h)	36	6.905	0.192			
Total	80					

^aCV(S)=1.68%, CV(S*V)=1.41%, CV(S*V*H)=1.50% , ^b** significant at 1% level, ^{ns} not significant

Appendix Table2: The effect of tuber sizes, tractor forward speeds and hopper fill level and their interaction on tuber MULTI (%)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F-Value	Tabular F-Value	
					5%	1%
<i>Main Plot Analysis</i>						
Replication (r)	2	0.03	0.02			
Tuber Size(S)	2	6.69	3.34	115.34**	6.94	18.00
Error(s)	4	0.11	0.03			
<i>Subplot Analysis</i>						
Tractor Forward Speed(V)	2	6.69	3.34	95.57**	3.89	6.93
Interaction (S X V)	4	0.64	0.16	4.57*	3.26	5.41
Error(v)	12	0.42	0.03			
<i>Sub-subplot Analysis</i>						
Hopper Fill Level(H)	2	11.29	5.65	137.71**	3.26	5.25
Interaction(S X H)	4	0.41	0.10	2.51 ^{ns}	2.63	3.89
Interaction (V X H)	4	0.46	0.11	2.80*	2.63	3.89
Interaction (S X V X H)	8	0.478	0.06	1.46 ^{ns}	2.21	3.05
Error(h)	36	1.465	0.041			
Total	80					

^aCV(S)=17.03%, CV(S*V)=18.71%, CV(S*V*H)=20.25% ^b** significant at 1% level, * significant at 5% level, ^{ns} not significant

Appendix Table 3: The effect of tuber sizes, tractor forward speeds and hopper fill level and their interaction on tuber MISSI (%)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F-Value	Tabular F-Value	
					5%	1%
Main Plot Analysis						
Replication (r)	2	0.03	0.01			
Tuber Size(S)	2	7.14	3.57	55.57**	6.94	18.00
Error(s)	4	0.26	0.06			
Subplot Analysis						
Tractor Forward Speed(V)	2	6.52	3.26	60.76**	3.89	6.93
Interaction (S X V)	4	1.57	0.39	7.30**	3.26	5.41
Error(v)	12	0.64	0.05			
Sub-subplot Analysis						
Hopper Fill Level(H)	2	4.98	2.49	64.62**	3.26	5.25
Interaction(S X H)	4	0.34	0.08	2.21 ^{ns}	2.63	3.89
Interaction (V X H)	4	0.42	0.11	2.72**	2.63	3.89
Interaction (S X V X H)	8	0.638	0.08	2.07 ^{ns}	2.21	3.05
Error(h)	36	1.389	0.04			
Total	80					

^aCV(S)=31.62%, CV(S*V)=29.04%, CV(S*V*H)=24.68% ^b** significant at 1% level, ^{ns} not significant

Appendix Table 4: The effect of tuber sizes, tractor forward speeds and hopper fill level and their interaction on QFI (%)

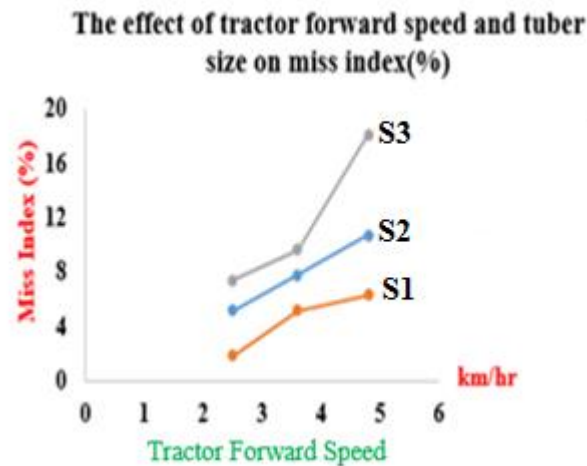
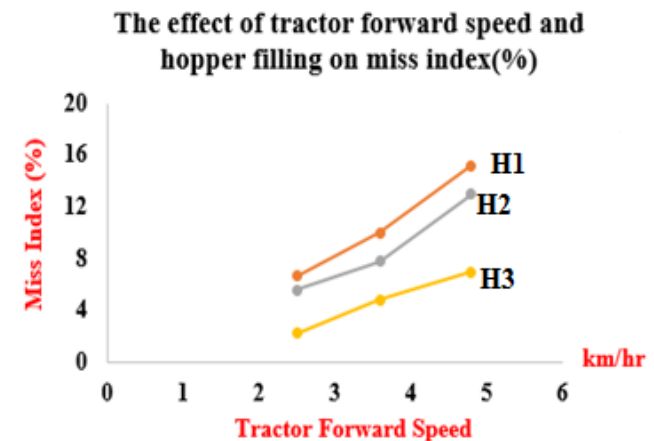
Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Computed F-Value	Tabular F-Value	
					5%	1%
<i>Main Plot Analysis</i>						
Replication (r)	2	0.04	0.02			
Tuber Size(S)	2	0.08	0.04	0.32 ^{ns}	6.94	18.00
Error(s)	4	0.48	0.12			
<i>Subplot Analysis</i>						
Tractor Forward Speed(V)	2	0.05	0.03	0.27 ^{ns}	3.89	6.93
Interaction (S X V)	4	3.65	0.91	9.43 ^{**}	3.26	5.41
Error(v)	12	1.16	0.10			
<i>Sub-subplot Analysis</i>						
Hopper Fill Level(H)	2	1.435	0.72	8.54 ^{**}	3.26	5.25
Interaction(S X H)	4	1.26	0.31	3.74 [*]	2.63	3.89
Interaction (V X H)	4	1.60	0.40	4.77 ^{**}	2.63	3.89
Interaction (S X V X H)	8	0.50	0.06	0.74 ^{ns}	2.21	3.05
Error(h)	36	3.02	0.08			
Total	80					

^aCV(S)=4.24%, CV(S*V)=3.79%, CV(S*V*H)=3.53%, ^b ^{**} significant at 1% level, ^{*} significant at 5% level, ^{ns} not significant

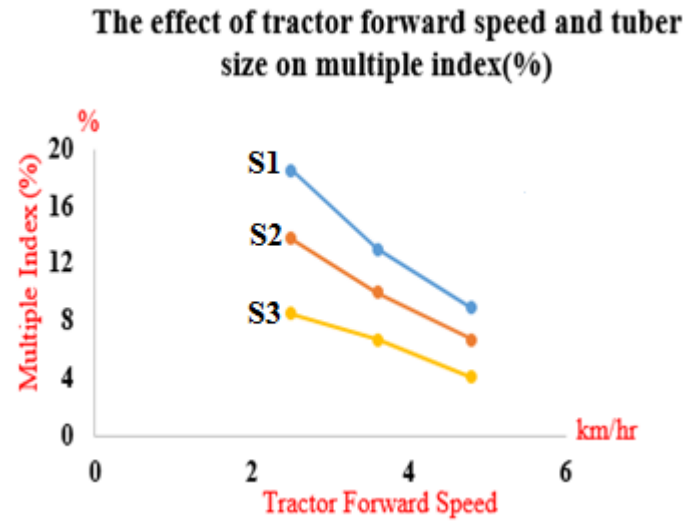
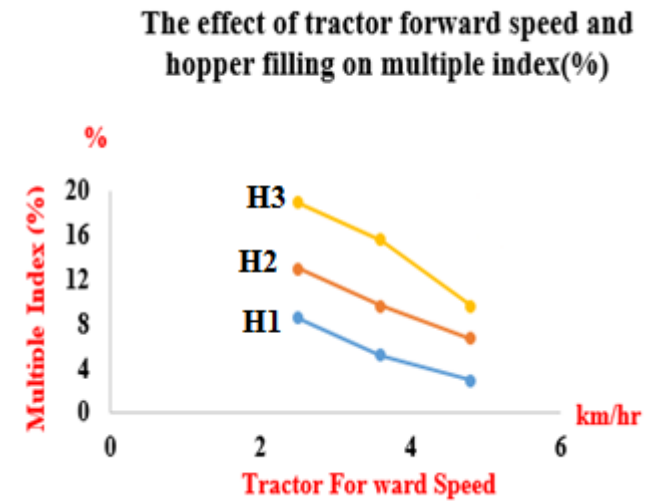
Appendix Table 5: Total cost of the potato planter, in ETB

Raw Material cost	Material Wastage 2.5%of 1	Machine cost	Labor cost	Overhead cost 5% of (3 + 4)	Profit 10 % of (1+2+3+4+5)	Sells tax 15 % of (1+2+3+4+5 +6)	Selling price (1+2+3+4+ 5 +6+7)
1	2	3	4	5	6	7	8
7325	183.13	3620	4320	397	1584.51	2614.45	20044.09

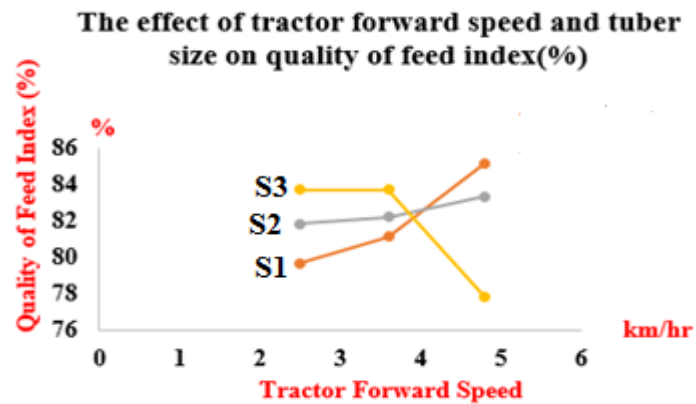
7.2. Appendix Figures



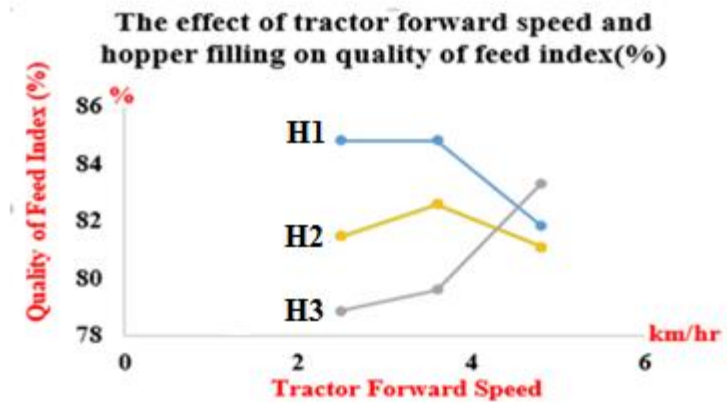
Appendix Figure 1: a) The effect of tractor forward speed and tuber size on MISSI (%) b) The effect of tractor forward speed and hopper filling level on MISSI (%)



Appendix Figure 2: a) The effects of tractor speed and tuber size on MULTI (%) b) The effect of tractor forward speed and hopper fill level on MULTI (%)



Appendix Figure 3: a) The effects of tractor speed and tuber size on QFI (%)



b) The effect of tractor forward speed and hopper fill level on QFI (%)



Appendix Figure 4: Testing prototype tractor mounted potato planter and measuring the spacing between tubers