Development and Performance Evaluation of Tractor-Drawn Broad-Bed Maker

Dawit Tilahun Tesema

A Thesis Submitted to the Department of Mechanical Engineering
School of Mechanical, Chemical and Materials Engineering
Presented in Partial Fulfillment of the Requirement for the Degree of Master of Science in Agricultural Machinery Engineering

Office of Graduate Studies
Adama Science and Technology University

June, 2022
Adama, Ethiopia

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Advisor: Dr. Amana Wako Koroso (Ph.D.)

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DECLARATION

I hereby declare that this Master thesis entitled ‘‘Development and Performance Evaluation of Tractor-Drawn Broad-Bed Maker″ is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Dawit Tilahun Tesema	____________	________________
Name of the student	Signature	Date of Submission

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled ‘‘Development and Performance Evaluation of Tractor-Drawn Broad-Bed Maker″ prepared under my guidance by Dawit Tilahun Tesema submitted in partial fulfillment of the requirements for the degree of Masters of Science in Agricultural Machinery Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Amana Wako Koroso (Ph.D.)	____________	__________________
Major Advisor	Signature	Date

APPROVAL PAGE FOR THESIS

I, the advisors of the thesis entitled "Development and Performance Evaluation of Tractor-Drawn Broad-Bed Maker" and developed by Dawit Tilahun Tesema, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Amana Wako (Ph.D.)	____________________	____________________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Dawit Tilahun Tesema have read and evaluated the thesis entitled "Development and Performance Evaluation of Tractor-Drawn Broad-Bed Maker" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfilment of the requirement of the degree of Master of Science in Agricultural Machinery Engineering.

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ACKNOWLEDGMENT

First of all, I would like to thank my God for his guidance and for giving me strength throughout the process of completing this thesis work. I am grateful to my advisor, Dr. Amana Wako for his invaluable advice and assistance throughout the thesis work.

Thankful to both Melkassa Agricultural Research Center and Debre-Zeit Agricultural Research Center for providing all the necessary logistics for the completion of this thesis.

I am also thankful to Melkassa Agricultural Research Center-Agricultural Implements Research and Improvement Center staff for their vital advice and assistance during the research work, especially to Mr. Teferi Getahun who assisted me technically during the manufacturing of the prototype, and Mr. Meseret Abebe, Mr. Dereje Alemu, Mr. Abiye Solomon and Mr. Manaye Ayalew for their co-advisor role throughout my thesis work. Mr. Kefyalew Woldesenbet, Mr. Frezer, Mr. Zemedkun Regassa, and Mr. Habtamu Megera who assisted me in conducting the field evaluation of the developed prototype deserve special thanks. Grateful to Mr. Tatek Wondimu who assisted me in the laboratory for the determination of soil physical properties.

The last, but not the least, gratitude goes to my loving family and friends who supported me throughout my studies.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATION

AGP	Agricultural Growth and Plan
ASABE	American Society of Agricultural and Biological Engineers
ASAE	American Society of Agriculture Engineers
ASTM	American Society for Testing and Materials
AUC	African Union Commission
AISI	American Iron and Steel Institute
BBF	Broad Bed and Furrows
BHP	Break Horse Power
Birr	Monetary Unit of Ethiopian
CAD	Computer Aided Design
C.V	Coefficient of Variation
d.b	Dry Basis
Dia	Diameter
DF	Degrees of Freedom
ds/m	Deci Siemens Per Meter
ENPC	Ethiopian National Planning Commission
FAO	Food and Agriculture Organization
ISO	International Organization for Standardization
L x H x W	Length, Height, and Width
LSD	Least Significance Difference
m a.s.l	Meter Above Sea level
M.B	Moldboard
MS	Mean Squares
NRCS	Natural Resources Conservation Service
q/ha	Quintal Per Hectare
RCBD	Randomized Complete Block Design
SDG	Sustainable Development Goal
SOLIDWORK	Engineering Drawing Software
USDA	United States Department of Agriculture
WRB	World Reference Base

ABSTRACT

In the highlands of Ethiopia, there are about 50 million hectares of land, with vertisols accounting for 16 %. Farmers have used traditional practices to overcome the water-logging problems of vertisols, all of which are insufficient to fully utilize the potentials of vertisols. The goal of this study was to develop and evaluate the performance of a tractor-drawn broad-bed maker. To complete this research work the following methodology was used: studying the physical properties of the soil, material selection, developing all parts of broad-bed maker, manufacturing and assembling the broad-bed maker components, performance evaluation of the broad-bed maker, data collection and organization, and finally data analysis. Frame, adjustable ridger, shank, three-point hitch links, and bed leveler are among the parts in the developed broad-bed maker. Modeling the machine component and data analysis were done using SOLIDWORKS 2021 and Statistix 8, respectively. The test parameters for the performance evaluation were the height of the bed, top width of the bed, and draft of the implement. The experiment was carried out in split-plot, with main plots arranged as an RCBD, operating speed is the main plot factor, with 3 levels, while depth of furrow is the subplot factor, with 3 levels. The physical parameters of the soil were tested and determined its soil textural triangle indicated clay: 13.34 % sand, 35.66 % silt, and 51 % clay at low depth, and 17.34 % sand, 29.66 % silt, and 53 % clay at high depth respectively. The electrical conductivity at different depth of the experimental plot was 0.171 ds/m and 0.224 ds/m respectively. The pH value of the experimental plot at different depth was 7.04 and 7.15 respectively. The average shear strength of the experimental plot was recorded as 0.956 kg/cm^2. 6.63 % moisture content, 4547 kpa penetration resistance, and 1.73 g/cm^3 bulk density were also observed from the test plot. The speed and depth of operation affect the height of the broad-bed. Tests were carried out on a test plot under varying conditions to optimize these two factors. According to the study results, the broad-bed reached its peak height at a speed of 2.9 km/h and a depth of 20 cm. To reduce the implement's draft, the speed was adjusted to 2.3 km/h and the depth of operation to 15 cm. Based on the optimal machine settings, the developed broad-bed maker was tested in the field, and the average height and top width of the bed achieved with the broad-bed maker were 23.6 cm and 124.3 cm, respectively. A minimum and maximum draft of 265.91 kgf and 388.03 kgf were required for the developed broad-bed maker. The fuel usage of the tractor-driven broad-bed maker was determined to be 3.44 l/ha. The designed broad-bed maker has a field efficiency of 72.9 %, and wheel slippage was determined to be 6.35 %. The cost of operation for a tractor-operated broad-bed maker was 1,254.21 Birr/ha, while the cost of fabrication for the BBM was 23,479.08 Birr. Finally, the machine has a capacity that is appropriate for its purpose; but, by adding additional features to the machine (such as a rotary tiller or a planter/seed driller), the machine's performance can be improved while all operations are completed in one pass.

Keyword: Broad-bed maker, Vertisol, Draft, Water-logging, Field performance.

CHAPTER ONE

1. INTRODUCTION

1.1. Background and Justification

Subsistence farming dominates agriculture in Africa, notably in Ethiopia, where a family produces barely enough food to support themselves (Gollin, 2014). Furthermore, agriculture is the primary source of employment, with 75 % of the population in Sub-Saharan Africa (SSA) countries and 80% in Ethiopia directly or indirectly involved (Moyo, 2016). However, output and productivity are extremely low due to the inefficient methods used (Solomon and Lehmann, 2017). Mechanization of the agricultural production system contributes to the achievement of the SDGs by boosting food production through land-intensive agriculture (Workneh et al., 2021).

Mechanization also increases farmers' cash revenue by reducing the time spent on land preparation, allowing them to engage in other money-generating activities. Ethiopia's government intended to encourage agricultural tractors in order to minimize post-harvest losses from 20 % to 5 % and boost the mechanical power index to 3.35 hp/ha by 2022 (ENPC-AGP II, 2015). Since Prime Minister Abiy Ahmed took office in 2018, agricultural mechanization has received more attention, and the African Union recently vowed to 'banish the hand hoe' by 2025 (FAO and AUC, 2018). Ethiopian farmers are struggling to overcome the challenges of the farming system facing them. One of the reasons is the poor financial strength of most farmers in Ethiopia. Many farmers cannot afford tractors and related machinery. Some of them use personalized recruitment services to complete their farming business on time while still using animal feed or traditional methods (Diao et al., 2016).

The Ethiopian highlands, which cover over half of the country's area, are suited for human and animal habitation. As a result, 95 % of the agricultural fields, 85 % of the human population (at a density of 64 people per km^2), and 77 % of animals are accommodated (Reij et al., 2013). Vertisols are clay-rich soils that shrink and swell in response to changes in water content (WRB, 2014). Ethiopia's highlands cover 50 million hectares, accounting for around 62 % of East Africa's highlands. Roughly 16 % of this region is made up of vertisols, and nearly the same amount has "vertic" characteristics (Headey et al., 2014). Standing water has a severe influence on agricultural yield, and farmers in the vertisol area have evolved traditional techniques to deal with it. Planting crops towards the end of the season after the surplus water has naturally drained to grow on the leftover moisture is one of the traditional strategies to cope with waterlogging concerns (Agegnehu and Sinebo, 2012).

In Ethiopia's highlands, over 2400m a s l, a unique method known as "guie" is used to cultivate barley on vertisols after leaving the region fallow for 5-8 years (Astatke and Jabbar, 2009). The burning of the soil changes the topsoil structure producing a coarser texture which facilitates better water movement and drainage and increases available phosphorous (Schoonover and Crim, 2015). Various cultivation techniques are also practiced using "maresha" to minimize the problem of waterlogging in vertisols (Hunduma and Admassu, 2020).

On gentle slopes, flatbed nursery preparation is normal, however an outside trench is occasionally dug to prevent floods. Planting crops including faba bean, field peas, barley, linseed, and sorghum with this approach is prevalent in dry places (Wubie, 2015). Drainage grooves are formed in flatbeds with "maresha" in various sections of Ethiopia's central highlands following planting. These drainage furrows have an average of 20 cm width and 15 cm depth (Debele and Deressa, 2016). In locations with a lot of rain, it's common to use "maresha" to produce ridges and furrows at a spacing of 40-60 cm. In this traditional ridge and furrow system, these grooves occupy 40-50% of the cultivated area (Hunduma and Admassu, 2020). Surface drainage of vertisols is aided in Ethiopia's central highlands by manually created channels and grooves. Making 3 to 4 passes with the "maresha" creates the seedbed. In the middle of the rainy season, the seeds fly and grooves are made with the "maresha" with a spacing of 0.8 to 1 m (Astatke and Jabbar, 2009). The soil is then gathered up in the furrows and placed onto the boards with the aid of family members. They not only build the plank and groove using this procedure, but they also cover the seeds. To drain water from cultivated areas, grass drains have also been built. This practice of manually building planks and furrows requires hard work on the part of the family (Doti, 2018).

1.2. Importance of Tractor Operated Broad-bed Maker

In Ethiopia, a diverse agricultural mechanization scenario prevails in the country due to the different sizes of farms and socio-economic inequalities (Workneh et al., 2021). In the growing trend of power-operated machines used by farmers nowadays, the availabilities of tractors ranging from 50-100 hp are viable. The large broad-bed machine was used to build the bed on the field faster than previous methods, but the tool price and running expenses were too expensive for small landholder farmers. It has been discovered that using large-size bed makers on a regular basis causes soil compaction, which makes crop development harder. Manual broad-bed making can produce clean results, but it is a laborious operation that requires more effort, and a severe labor scarcity during the peak season causes bed making to be delayed. This manual bed-making method was performed by child and women labor to make a bed, and it is a time-consuming operation (Doti, 2018). When compared to animal-drawn and traditional methods of bed making, tractor-drawn broad-bed makers help speed up operations. Small landholders, whether owned or leased, require efficient yet low-cost farm tools and equipment.

1.3. Statement of the Problem

Ethiopia has 50 million hectares of land in the highlands which cover about 62 % of the highlands of East Africa. Of this area, 16% are estimated to be vertisols (Muluken et al., 2021). The highlands cover 43 % of the total landmass of the country but account for about 95 % of all cultivated land (Wassie, 2020). Hence, the importance of vertisols in the country is unquestionable. Most vertisols, on the other hand, suffer from excess water and poor workability, as well as being underused and mostly used for dry season grazing (Doti, 2018). Potentially, vertisols are productive soils, but they are not easy to cultivate due to their poor internal drainage and resultant flooding and water-logging during the wet season which contributes to lower crop yields (Ayana, 2014; Hunduma and Admassu, 2020; Muluken et al., 2021).

Farmers have been using traditional practices such as growing tolerant (usually low yielding) crop varieties, late planting, traditional ridges and furrows, hand-made broad beds and furrows, and soil burning practices to overcome the water-logging problems of vertisols, all of which are insufficient to fully utilize the potentials of vertisols (Ayana, 2014; Wubetu, 2017). The traditional system of late planting of crops has also often resulted in poor crop yields and soil erosion (Doti, 2018).

In general, some unpublished research, and stakeholders (Research center) report showed that, farmers living in the vertisol dominant areas use traditional and inefficient practice to manage water-drainage problems. This leads to low crop yields and high cost of land preparation. Some other problems include: -

- The attention given to the adoption of improved farm machinery (including a modified BBM technology) to date was limited (Doti, 2018).
- Implements previously made by MARC-AIRIC for management of vertisol have problems, such as heavyweight and shallow depth of operation.

Due to the above problems found from literature and stakeholders, the need of developing BBM is very important for vertisol dominant areas and maintain land efficiency for the farmer. The contribution of this work is to tackle the problems by developing the broad-bed maker technology following the manufacturing process or development of the prototype until it comes to the filed performance test of the developed prototype.

With the above point in mind, the research was carried out with the following objectives.

1.4. Objectives

1.4.1. General objective

The overall objective of this research was to develop and evaluate the performance of a tractor-drawn broad-bed maker for vertisol area.

1.4.2. Specific objective

- To develop a tractor drawn broad-bed maker.
- To test the performance of developed prototype machines.
- To evaluate the performance of developed prototype machines.

1.5. Significance of the Study

The development and testing of tractor-driven broad bed makers can close the mechanization gap between harrowing and sowing operations more quickly. One of the primary reasons for low productivity is insufficient power availability on the farm, inadequate supply of farm employees, and low-level of agricultural mechanization. This is especially true for Ethiopia. To fulfill the food requirements of the rising population and fast industrialization, modernization of agriculture is inevitable. Modern technology, better seed and fertilizers, efficient and cost-effective agricultural equipment, machineries, and appropriate farm power are all critical. Improper seedbed preparation, planting, and harvesting reduce production. Mechanization allows for conservation by assuring better distribution, minimizing the amount of delayed input required for improved response, and preventing losses or wasting of inputs used. Mechanization reduces the unit cost of production through higher productivity. Bed making is an important operation carried out after harvesting, plowing, and harrowing. It is the art of collecting the soil from the plowed field. Also, high labor wages coupled with its scarcity during the period of bed making leads to an increase in the cost of bed making and simultaneously the cost of field preparation which reduces the net profit of the framer. This operation is done with the help of women, child labor, etc. Such types of operations required more labor (labor-intensive activity) and time consuming and increase the cost of operation. The importance of developing the broad-bed maker was to decrease high labor wages and cost of bed making during the peak season and it is economically suitable for small land holders, save time, and decrease drudgery for farmers family. And also, encourages the farmer to use his land on time for planting.

1.6. Scope and Limitations of the Study

Many of the farmers cannot afford the tractor and its matching machinery. Some of them used custom hiring services to complete their farm operations in time and the remaining used animal power or manual bed making. Now a day's bed-making is done by the traditional methods such as manually bed-making after plowing or harrowing operations. Based on the intended development objectives, this study limited to the development and performance evaluation of a broad bed maker for tractor successfully operation for water-logged area; studying some soil physical properties (including soil texture, bulk density, moisture content, pH, EC, soil strength, and penetration resistance of the soil). Also, all the processes need to the development and fabrications of the broad-bed maker at local workshops. The bed maker development was considered different crop (wheat, and teff) as a boundary of studies. As a result, the designed machine should have a straightforward design and be simple to manufacture and operate. The machine's price should be affordable and within reach of most farmers.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Advantages of Broad-bed Cultivation System

Khambalkar et al. (2014), studied the broad bed-furrow planter in winter season for dry land crops. The metering mechanism for broad bed furrow planter was edge drop cell feed inclined plate. The shape of seed and fertilizer boxes were trapezoidal and used to carry seed and fertilizer during the sowing operation. Ridger or bed shaper was used to convey the loose soil and shift it on top of the bed. With a 30 cm furrow width, 25 cm furrow depth, and 10 cm protection distance for chickpea, 30 cm and 10 cm row spacing and plant spacing were maintained in the broad bed furrow technique of planting. The results revealed that wide beds conserved more moisture than standard sowing methods. In addition, the broad bed furrow technique of planting increased yield by 12.50 % and 10.71 % in chickpea and safflower, respectively, as compared to the typical flatbed method of sowing. For some crops, the broad bed furrow approach proved more practical than the usual way of sowing.

According to Ayana (2014), broad bed and furrow was superior to other land preparation methods in terms of yield and yield components, indicating that enhanced land preparation methods on vertisols permit larger yields.

Choudhary et al. (2015), develop and evaluate the performance (in terms of system productivity, water productivity and profitability) of conservation agricultural technologies (like permanent narrow and broad-bed planting and residue management under zero tillage with relay sowing under different plant spacing) under an irrigated cotton-wheat system. Results indicate that seed cotton yield in the plots under PB-B was higher compared with other treatments. Similarly, plots under PB-B had significantly higher number of spike, spike length, number of grain/spike, test weight and wheat grain and straw yield than remaining treatments. Therefore, it concluded that cotton-wheat system under permanent beds with residue retention under wide spacing and relay sowing of wheat in two pairs per bed increase productivity of system.

Dabhi et al. (2016), conducted a field test to evaluate the performance of three types of mini tractor pulled tillage equipment for seedbed preparation. Using a Randomize Block Design with five replications, the Mahindra-Yuvraj (15hp) small tractor and matching tillage instruments (cultivator, M.B. plough, and rotavator) were utilized to prepare the seedbed. Travel reduction (wheel slippage), draft, and speed of operation were all examined, as were drawbar power, soil volume disturbed, fuel consumption, field efficiency, and soil pulverization. In comparison to the other treatments in terms of the characteristics examined, the single pass rotavator (T4) was both cost effective and performed satisfactorily for seed bed preparation. Tillage operating costs were 311.25, 327.91, 410.54, and 280.17 rupees per hour for T1: Cross cultivation by cultivator, T2: M.B. plough + cultivator, T3: 2 x rotavator, and T4: 1 x rotavator, respectively. The rotavator's single pass (T4) has the lowest operational cost. In terms of efficiency, soil pulverization, and total hourly cost, the small tractor drawn rotavator outperformed all other seed bed preparation devices.

According to Singh et al. (2016), on a mechanized farm, a bund is formed by a bund former that is either driven by a tractor or by animals for irrigation and to demarcate the fields. Bund formers used by tractors are usually disc, mouldboard, or forming board types. When a bund is constructed with a typical bund former, the shaping and packing of the bunds is done manually with a spade and feet. This is a time-consuming and labor-intensive activity. A tractor-operated bund former cum-packer was created and developed to alleviate the drudgery of these activities. An attempt is made to integrate bund formation and packing processes in a single pass, which would save even more fuel, time, and other resources. The bund former-cum-packer was made up of a disc type bund former, a rectangular tool bar frame, and a packing unit that were all commercially available (concentric cylindrical roller, drive shaft, conical discs, compressive shanks etc.). Field testing of the bund produced by the bund former-cum-packer revealed no water seepage or bund breaking during flood irrigation. At a tractor speed of 2.93 km/h in 2 and low gear, the field capacity with the equipment was 1.4 ha/h. The bund former-cum-packer can minimize labor requirements for bund packing by up to 96 %. The equipment's overall utilization has the potential to boost resource productivity by 38 %.

Verma et al. (2017), introduced broad bed planting technology in the study area to compare it with the conventional sowing of soybean by flatbed methods. Six-row broad bed furrow machine was used to plant soybean having top bed width of 2.35 cm. Result showed that growth character (plant height, number of branches per plant and number of root nodules per plant) and yield contributing character viz., number of pods per plant, seed yield weight per plant, seed index, seed yield, straw yield and harvest index (%) were found higher in broad bed furrow compared to the normal flatbed sowing which subsequently resulted in yield enhancement to the extent of 28.38 % for soyabean crop. The average yield in broad bed furrow method recorded 15.20 q/ha.

Tewabe et al. (2020), field experiments were conducted to determine the optimal range of bed width under the bed and furrow irrigation technique of wheat at Koga (clay soil) and Rib (loam soil) irrigation scheme, North West Amhara, Ethiopia. It was found that bed width on a raised bed in different soil texture had significantly affected yield and water productivity of wheat. The result indicated that 60 cm to 80 cm bed width at Koga showed up to 26 % yield advantage and saves about 25 % irrigation water as compared to farmer practice. Moreover, using 100 cm to 140 cm bed width at Rib (loamy soil) has up to 27 % yield advantage and saves 28 % irrigation water as compared to farmer practice. Therefore, we concluded that the cultivation method under different soil texture and raised bed width affect yield and water productivity of wheat.

Du et al. (2021), developed a raised bed planting (RBP) pattern to alleviate the profound impacts of waterlogging stress on wheat production. The results showed that RBP significantly increased soil water drainage and reduced the soil water content. The reduced waterlogging stress promoted wheat seedling establishment and root growth, accelerated stem and tiller development, and delayed late-season root and leaf senescence, resulting in 11.3 % and 14.1 % higher grain yields in Fengtai and Guohe, respectively. Furthermore, RBP required fewer inputs and produced more outputs, generating 63.1 % and 59.6 % more net income in Fengtai and Guohe, respectively. Based on this study, RBP can be considered an effective, sustainable soil tillage practice to reduce waterlogging stress and thereby increase wheat productivity and profitability under future waterlogging conditions.

As a result, vertisols are now underused in Ethiopia. Vertisols are capable of providing several times more food and cattle feed than they do now, because to their huge moisture-holding capacity and relatively high fertility. Therefore, removing vertisol constraints to crop production in both cultivated and uncultivated areas will have very high importance in food deficient Ethiopia. If food self-sufficiency is to be achieved in Ethiopia, vertisols which cover immense land mass of the country, needs to be put under cultivation with proper excess water draining innovations and integrated nutrient management strategies (Wubetu, 2017).

2.2. Available Broad-bed Makers

Astatke and Jabbar (2009), developed the first and second version of a broad-bed maker (BBM) made from the maresha (Figure 1) and (Figure 2). The first version was a broad-bed maker (BBM) made from the maresha (Figure 1). The maresha's main beams were cut down to roughly 90 cm and linked with a basic wooden frame. Two flat maresha wings were replaced with mouldboard shaped wings, with two bigger ones throwing soil to the center and two smaller ones throwing it outside, creating beds and furrows. Because this equipment could only be used to shape the soil, the field had to be plowed three or four times with the maresha first. Depending on the type of wood used, the tool weighed around 35 kg. Farmers, on the other hand, found it too heavy to manage and too large to transport to and from the field when they tested it out in the field. In remote places, acquiring a spanner and 12 bolts to assemble the wooden BBM frame was also difficult.

Figure 1. The second version of broad-bed maker

The current version of the BBM is universally regarded as effective and acceptable, having been tested on farms for several years. It is built around a typical wooden frame plow to which the "maresha" metal plow-share with its land-shaping mouldboard is connected. Two "mareshas" are joined in a triangular construction and hung on a crossbar about 120 cm apart (Figure 2). In the traditional way, the top ends of the "maresha" beams are linked together and fastened to the yoke. Each of the inner flat wings has a steel mouldboard wing connected to it.

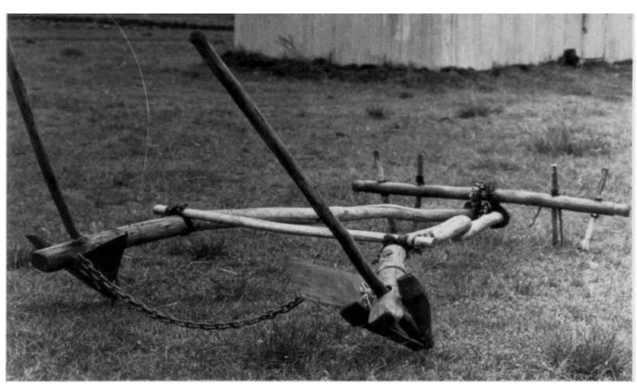


Figure 2. The latest version of the broad-bed maker.

Taking into consideration the need for water draining implement for farmers of vertisol areas, Melkassa Agricultural Research Center-Agricultural Implements Research and Improvement Center (MARC-AIRIC) has designed, developed, and disseminated a tractor attached broad bed and furrow making implement (Figure 3) as I observed from the center. However, the implement is heavy (concrete blocks clamped on the frame), making shallow furrow depth and difficult to manage. Due to these reasons, the implement failed to achieve the intended performance.

Ethiopian farmers have limited cash income, so any improvement of tools and farming methods must consider this and make the economy a priority (Mottaleb et al., 2016). As a result, implements and technology must be reasonably priced so that farmers may afford them and utilize them effectively. These days there are several small to medium horsepower tractors owned by farmers, which can be used for farm operations, such as land preparation. In addition, there are several two-wheel and medium horsepower tractors disseminated, to rural youths and common interest groups, by governmental business companies, like Ethio-Engineering Group (EEG) formerly Metals and Engineering Corporation (METEC) and governmental projects like Agricultural Growth Program-II. Developing an efficient and affordable tractor-attached broad bed maker has paramount importance to farmers living in areas where the dominant soil type is with vertisols.

Figure 3. AIRIC made broad bed and furrow maker

(Source: Photo taken by me MARC-AIRIC, Unpublished, 2013)

Gadge and Shinde (2016), developed a raised bed preparator for the formation of the raised bed for the vegetable crop as well as horticulture crop to overcome the problem of waterlogging and improve soil structure on cropping soils in the high rainfall zones.

Patil (2016), designed and developed a power tiller operated raised bed seed cum fertilizer drill for dry paddy. The field test of developed seed cum fertilizer drill for dry paddy was carried out at four different speeds i.e., 1, 1.5, 2 and 3 km/h and found that 2 km/h speed shows the best result and was selected for sowing operation. It was observed that the average depth of seed placement was 4.2 cm for raised bed system and 3.3 cm for flatbed system and fertilizer was placed at a 6.1 cm for raised bed and 4.9 cm for the flatbed system. The average top width, bottom width and depth of bed formed were 58, 78 and 11cm, respectively with a furrow width of 22 cm. The 185 and 143 plants per square meter area were observed for the raised bed and flatbed system. In the operation of a raised bed system at 2 km/h speed, the theoretical field capacity, effective field capacity and field efficiency was observed as 0.160 ha/h, 0.125 ha/h and 78.37 %, respectively whereas during flatbed system 0.120 ha/h, 0.095 ha/h and 77.29 %, respectively. The power required for operation was found to be 0.360 hp for a raised bed system and 0.298 hp for the flatbed system.

Singh et al. (2016), designed and developed a tractor operated bund former-cum-packer. An attempt is made for enabling the combined operations of bund forming and packing in single pass that can save fuel, time and other resources further. The bund former-cum-packer consisted of commercially available disc type bund former, rectangular tool bar frame, and packing unit (concentric cylindrical roller, drive shaft, conical discs, compressive shanks etc). The bund formed by bund former-cum-packer was field tested and found neither water seepage nor breakage of bund during flood irrigation. The field capacity with the equipment was 1.4 ha/h at tractor speed of 2.93km/h in 2nd low gear. The bund former-cum-packer can reduce about 96 % dependency on labour requirement for packing the bund. Overall use of the equipment is having potential to increase the resource productivity by 38 %.

Joshi and Shrivastava (2017), designed the modification for tractor drawn raised bed seed drill with two beds forever machine, a furrow dresser was and for adoption of raised bed technology for farmers, in clay loam soil (vertisol). This machine was evaluated and compared with the performance of a raised bed drill with three bed furrows, zero till drill and conventional practices at Jawaharlal Nehru Agricultural University farms for the chickpea sowing. It was found that the total time and cost required for making raised beds and sowing operations by raising bed drill was 1.42 h/ha and 291.79 birr/ha, which is 17.44 % and 20.22 % less time required than conventional sowing practices and zero, till drill practices respectively. The average yield by raising bed seed drill was 1211.3 kg/ha. Whereas, by conventional practices and tractor drawn zero till drill was 1127.83 kg/ha and 1137.8 kg/ha, respectively. The soil conditions were also found better in the case of the tractor-drawn raised bed seed drill machine.

Kumar et al. (2020), developed a tractor-drawn single-row/double-row raised-bed pulse-planter for pigeon pea during 2014-2019. Developed pulse-planter was field tested, refined and validated at Agronomy Research Farm, New Delhi during 2017-2019. On an average, the variation in grain yield under raised-bed double-row manual-sowing (RB - DR-MS) and raised-bed double-row pulse-planter sowing (RB-DR-PPS) was 1.18 % while in raised-bed single-row manual-sowing (RB-SR-MS) and raised-bed single-row pulse-planter sowing (RB-SR-PPS), it was 2.43 %. Grain, stover and biological yield followed the trend of RB-DR-MS>RB-DR-PPS>RB-SR-MS>RB-SR-PPS>FB-DRMS>FB-SR-MS, respectively. Overall, RB-DR-PPS and RB-DR-MS were equally best performers with respect to grain and stover yield in pigeon pea. Thus, 'SR/DR-RB-PP pulse-planter' holds great promises in mechanization of pigeon-pea sowing both in single-row and double-row raised-beds for improving the pigeon-pea acreage and productivity coupled with time-saving and drudgery reduction so as to enhance farm productivity and farm incomes.

Lhamu et al. (2022), designed and tested a bed-making implement to be attached to a tractor machine to determine the dimensions of the bed formed specifically to suit the available plastic mulch width for cultivation of vegetable crops. A 34 HP tractor was used as a power source for the bed making implement. The machine was tested at three different tractor forward speeds of 1.89, 2.54 and 5.04 km/h to record the width and height of the bed formed at these corresponding forward speeds. The results indicate that although the bed width increased with an increase in forward speed (76.89, 80.11 and 87.22 cm for 1.89, 2.54 and 5.04 km/h, respectively), the optimum bed width suitable for vegetable cultivation using the available plastic mulch was 80.11 cm with a bed height of 25.33 cm formed at the forward speed of 2.54 km/h. The machine field capacity recorded at the forward speed of 2.54 km/h was 3.80 acre/day, while that of a person’s capacity to make the bed of the same dimension manually was 0.02 acre/day.

2.3. Development and Performance Evaluations of Broad-bed former

Verma et al. (2017), presented broad bed planting technology and compared it to traditional flatbed soybean sowing. To plant soybean, a six-row broad bed furrow machine with a top bed width of 2.35 cm was employed. The number of pods per plant, seed yield weight per plant, seed index, seed yield, straw yield, and harvest index (%) were all found to be higher in broad bed furrow compared to normal flatbed sowing, resulting in a yield increase of 28.38 % for the soyabean crop. In the broad bed furrow approach, the average yield was 15.20 q/ha.

Dixit et al. (2018), developed and evaluated tractor operated wide bed former prototype. The machine comprises of a rotary tiller and a bed forming setup. It forms bed of 1m top width which is suitable as per the track width of an average sized tractor in India. The height of the beds formed is 130 mm whereas the top and bottom width of channel formed on both sides of the bed is 330 and 40 mm respectively at soil moisture content of 12.5–16 % (d.b). The forward speed of 2.75 km/h was observed to be suitable for proper bed formation. The average fuel consumption of the machine was 5.9l/h. The average bulk density of soil before and after the bed formation was 1.46 and 1.63 g/cc respectively. Field capacity of the machine was found to be 0.31 ha/h. The machine resulted in 93.8 % labour saving and 80.4 % saving in cost of bed preparation as compared to conventional farmer practice. Overall performance of wide-bed former was found to be satisfactory.

Muluken et al. (2021), the finding, in general, revealed that broad bed and furrow (BBF120) gave the highest mean grain yield and biomass of wheat; and it could potentially drain excess rainfall without causing significant soil loss. The capacity of draining more runoff is desirable to tackle the major problem of the study area which is surface waterlogging. So, BBF120 is the best option for draining excess runoff and accordingly maximizing crop yields of wheat.

Mustaqimah et al. (2021), develop and test a bed former powered by a hand-tractor for upland. It was carried out in the experimental field (sandy clay loam texture) at a furrower depth of 15 cm and 20 cm with a tractor forward speed of 0.5 m/s. The bed's former design results have dimensions of length, width, and height of 1200 x 1000 x 820 mm. The performance test results showed an increase in tillage depth resulted in increased bed height, bed width, bed width, and slip. However, field capacity decreases with increasing tillage depth. The bed former's performance was found to be satisfactory in general.

Singh et al. (2021), designed and developed a tractor operated rotary assisted broad bed former-cum-seeder at ICAR- Central Institute of Agricultural Engineering, Bhopal, India. Rotary tillage followed by broad bed formation, sowing and reshaping of bed was by used dumbbell shape re-shaper. Performance of developed machine was evaluated and compared with flatbed sowing for soybean and wheat crops at ten randomly selected farmer's field in vertisols. The field capacity and fuel consumption of developed machine were found as 0.32 ha/h and 15 L/ha respectively. The grain yield under broad bed seeded soybean was found 0.96t/ha, however, conventionally sown soybean yielded 0.71 t/ha. Thus, the yield gain in soybean crop under broad bed technology was found 35.95 %. The yield of broad bed and conventionally sown wheat, were found 4.99 and 4.15 t/ha, respectively. Therefore, grain yield increased by 20 % in Wheat crop due to the sowing with developed machine under broad bed condition. This machine saved 17.3 % cost of operation as compared to the traditional flatbed sowing.

2.4. Machine Components

A. Frame

Smith (1997), had given some guidelines in the fabrication of the frame. The frame was usually made of mild steel angle, well braced and reinforced at the corners. The frame needed to be strong enough to prevent sagging and to hold the parts in alignment as all parts were connected to the frame.

Achutha et al. (2016), developed a carrier multipurpose frame which had the facilitates of holding and operating, sowing equipment, sprayer, weeding tools and inter- cultivation tools.

Mandloi et al. (2017), developed attaching plough and clod crusher on multipurpose frame, it was able to prepare the seed bed in one pass saving 20 % of operating cost required in sandy loam soil.

Ghadge et al. (2020), developed proper designed tool which can perform several operations and selection of the components required on the machine to suit the need of operations. A multipurpose frame with wheels having the facility to hold tools such as furrow opener, hoe blade, seed covering plate, V-blade and cultivator tine to suit the small and marginal farmers.

B. Soil cutting blades

Ibrahmi et al. (2017), illustrates an advanced analytical method combined with computer-aided design software in order to study the effect of the geometric parameters (α, β, q, and m) on the 3D surface design of the cylindroidal mouldboard ridger. A comparison between the cylindroidal and the cylindrical mouldboard ridger was investigated for only the effect of the geometric parameters (β). The study showed that the increase of the cutting angle (α) and lifting angle (β) generates different mouldboard ridgers with a larger cutting edge and produce the uprising of the mouldboard ridger body relative to the direction of the tillage, respectively, which increases the consumed energy. However, the increase of the geometric parameters (q) and (m) reduces the radius curve of the mouldboard ridger, which directly affects both the inversion process of the soil and the consumed energy.

Singh et al. (2017), Studied the effect of different types of furrow opener (IISR furrower, IISR deep furrower and conventional type ridger) at different depth and speed of operation on soil penetration resistance, ridge height, specific draft, soil disturbance and germination percentage and to select the best furrow opener for establishment of sugarcane crop. Soil disturbed and draft force requirements increased significantly with the increase in operation speed and depth of furrow in all the furrow openers. The significantly higher germination percentage after 30 and 45 DAP was observed with IISR deep furrow opener at 250 mm depth. The lowest soil penetration resistance, minimum specific draft and better germination were found with IISR deep furrow opener.

Wang et al. (2017), designed the hanging unilateral rotary tillage compacting ridger in order to improve the quality and the efficiency of ridging operation in paddy field, and to reduce the labor intensity, in view of meeting the agronomic requirements of rice planting in the northeast region of China. Test results showed that the forward speed of the ridger was 1.33 km/h, the rotational speed was 525 r/min, and the average of ridge density was 2160 kPa, the variation coefficient of ridge height was 4.01 %. On the basis, the field test was carried out, and the test results showed that the ridger was characterized by its compact-sized reasonable structure and simple operation. And its ridge had good quality, which was solid and smooth and could meet the requirement of paddy field production.

Kumar et al. (2020), developed low-cost ridging technology which is suitable for small and medium farmer under stress environments. The crop, machine and operational parameters were identified and selected and the animal drawn maize ridger was developed and evaluated for its performance in actual field conditions. The ridge dimensions were optimized top width, bottom width and ridge height 12.75, 43.75, and 16 cm respectively with total volume of soil cover 452.31

cm^3 considering plant height and row to row spacing. The average draft of the ridger 69.81 kg-f was observed during ridging operation.

C. Share rake angle, wing shape and wing angle

Ismail and Ismail (2013), developed a soil layer deformation model during wide raised bed's construction. The raised beds in the wide ridge furrow system during vegetables planting was identified by turning the soil layer using two opposing moldboards. Due to the interaction between the two opposing moldboards on soil, a furrow slice shifting on the surface of the moldboards undergoes a certain bending and twisting defection, which causes loosening of soil particles in the upper parts and compressing of soil in the lower parts causing an additional crushing. The height and width of wide ridge can be adjusted for setting angles of moldboard share (20, 30 and 40°), operational depths (10, 15, and 20 cm) and forward speeds (3.9, 4.5, 5.0, and 6.9 km/h) in sandy soil. Measurements were compared and found that increasing setting angle from 20 to 40° the raised beds height increased by 16.6 %, while the upper width decreased from 42 to 20 cm and the wall bed sloping angle decreased by 59.3 % also the cross-section area and fertilizing depth increased by 37.4 % and 22.2 % respectively.

Marey (2015), conducted field experiments to investigate the effects of share rake angles (20^o, 25^o and 30^o), opener wing angles (35^o and 45^o) and wing shape configurations (straight and curved) on the furrow profile characteristics, and evaluate planting methods the wing shape and angles on the emergence, sugar percentage, root and sugar yield, applied water and water use efficiency. The results showed that the curved shape and the wing angle of 45^o produced wider furrows than those produced by the straight shape and 35^o wing angle. The maximum emergence percentage, root and sugar yields, sugar percentage and water use efficiency are associated with a wing angle of 45^o and the curved wing shape.

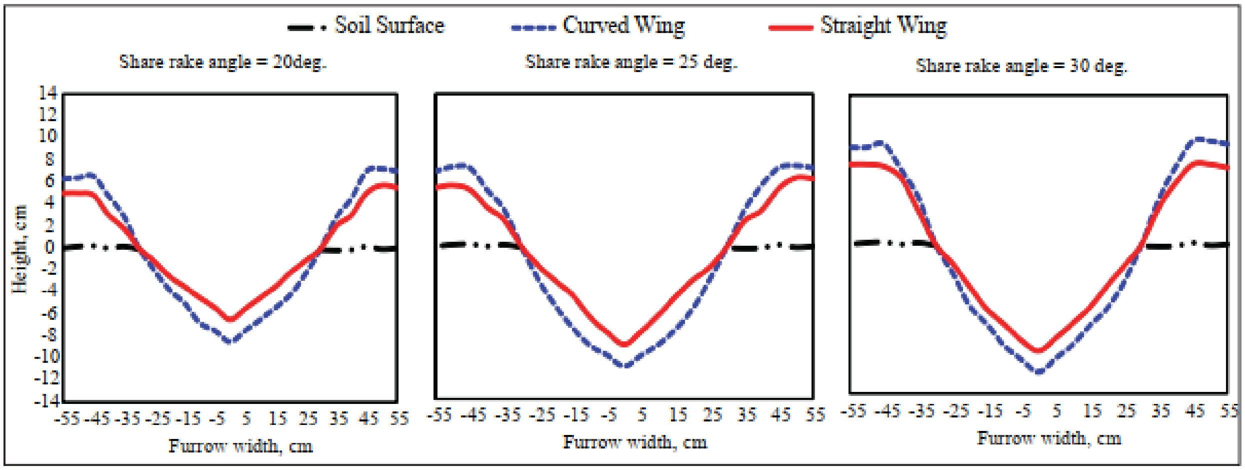


Figure 4. Furrow profile as influenced by share rake angle and wing shape

2.5. The Research Gaps

In general, the research gaps observed from literature and from stakeholders that could be needed to be filled by developing the broad bed maker regarding this research paper was presented as follows. A study described by Doti (2018) reported some problems mentioned by farmers in using BBM. Some farmers reported that the equipment was too heavy for their animals (this could be partly due to a feed problem, as the time for planting with BBM coincides with the end of the heavy cultivation period and low feedstock), while others stated that it was impossible to make an effective channel and properly cover seed when the soil was too wet.

Doti (2018), stated also despite the difficult of using vertisol for agriculture through traditional methods, farmers have widely rejected earlier broad bed maker technology due to its heavy weight, needs for trained personnel for assemblage and other factors. Also, he mentioned most adoption studies in Ethiopia have generally focused on better crop varieties and their related agronomic practices, however attention has been paid to the adoption and development of improved farm machinery to date is limited.

With oxen power, it is difficult to maintain the required furrow width and depth, and bed width using an oxen-drawn implement. In addition, Farmers rejected earlier models because of high draft force, heaviness, poor performance, etc. Aybar BBM addressed all complaints of farmers and crop yields increased by 300 % (Melesse, 2021), but this must be changed with tractor operated for more efficiency. The BBM's job was to build elevated seedbeds and furrows more efficiently and effectively, avoiding waterlogging and enabling early planting of an enhanced cereal variety cereal crop, which could then be followed by a second crop of pulses in the same growing season. but the study area is much affected by waterlogging problems due to the nature of the soil (Ayana, 2014).

Wubie (2015), stated also that despite a concerted effort during the last two decades to develop improved technologies for the soils, land preparation for agricultural productivity and sustainability remains a major challenge. In addition to technical difficulties associated with their nature and deep-rooted poverty and illiteracy, lack of farmers ‘participation is believed to have hampered the development and adoption of robust technologies. The challenge facing the soil management research in Ethiopia is thus double fold: development of technologies that swiftly increase agricultural production and ensure judicious use of the land resources.

Hunduma and Admassu (2020), sated also that vertisols have high crop production potentials, they are underutilized due to inadequate land, water and crop production management technologies and lack of basic information for developing interventions suited to farmers' immediate requirements.

In general, tractor-operated broad bed makers may close the mechanization gap between harrowing and sowing operations more quickly than other methods. A survey of the literature reveals that a tractor-operated broad bed maker has produced good results. This demonstrates the pressing necessity to deploy this sort of tool. The development of a tractor operated broad bed maker is a requirement of today's farming in order to decrease drudgery in the operation while saving time and labor, doing work efficiently, and covering more land in less time.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was conducted both on-station and on-farm. On-station it was in Melkassa Agricultural Research Center (MARC), 17 km South of Adama, or it is located 117 km South-East of Addis Ababa, Ethiopia for the fabrication and preliminary test of the prototype. The area is located at 8° 24’ N latitude and 39° 21’ E longitudes at an altitude of 1550m a s l. On-farm it was in Debre-Zeit Agricultural Research Center (DZARC) farm. Debre-Zeit is located 47 km southeast of Addis Ababa. The area is located at 9° 44’ N latitude and 38° 58’ E longitudes at an altitude of 1900m a s l in the central high land of Ethiopia. It has an annual rainfall of 851 mm of which 84 % is in the long rainy season (June to September). From October until February, the dry season lasts. With a mean relative humidity of 61.3 %, the average annual maximum and lowest temperatures are 28.3°C and 8.9°C, respectively.

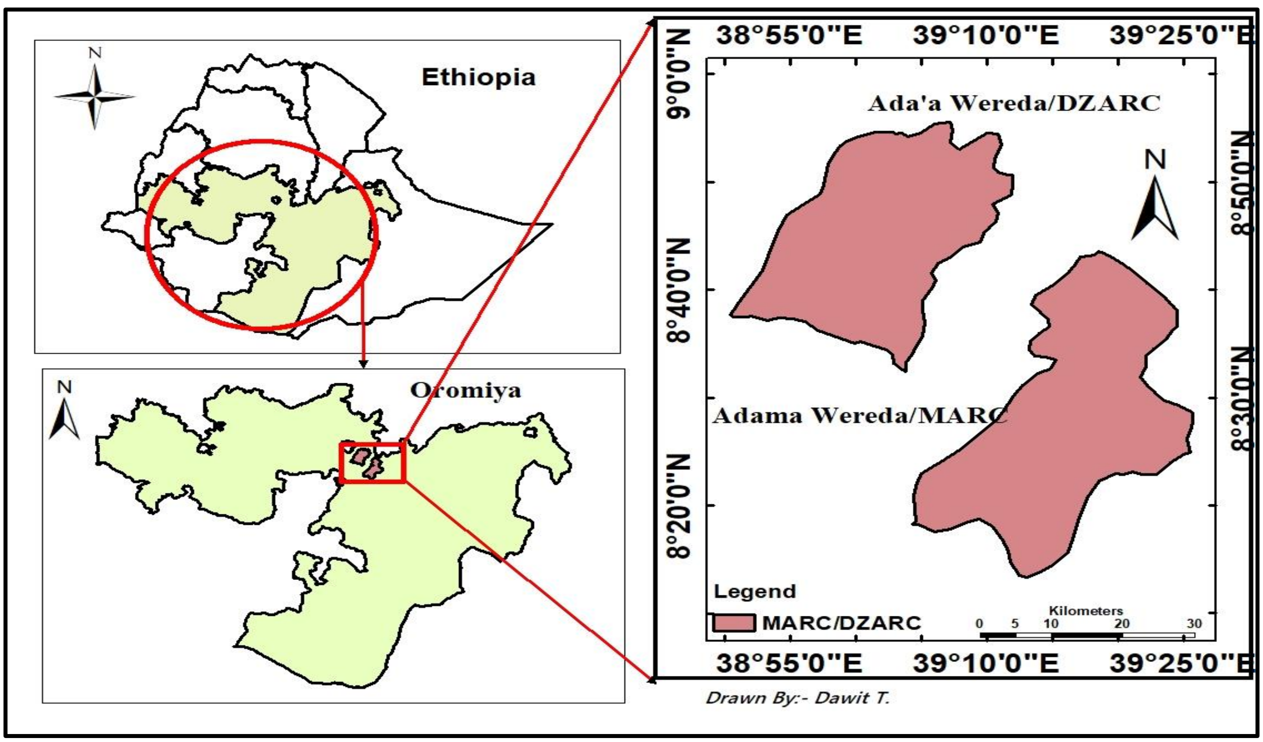


Figure 5. Maps of the study area.

3.2. Design Consideration

The following parameters was considered during development and manufacturing of the prototype for small to medium-size tractors.

- Agronomical requirements.
- Physical and economic considerations.

3.2.1. Agronomical requirements

A machine was developed by keeping in mind the various agronomical requirement of the crop.

- Type of crop: teff or/and wheat.
- Suitable for planting method: either broadcasting or row planting/ drilling (row to row distance of both crop is 20 cm).
- Condition of field: well-prepared field or after harrowing is done.
- Type of soil: vertisol (heavy black clay soil).

3.2.2. Physical and economic considerations.

- The machine should have a straightforward design and be simple to use.
- The price of the machine should be affordable to farmers.
- The farmer or village artisans should be able to easily fix it.
- The total power requirement should not exceed the power available from available medium-size hp tractors.
- Drawbar horse power (DBHP): 60 % of BHP of tractor.
- Speed of operation: 1st, 3rd, and 4th high gear of tractor with governing throttle valve.

3.3. Physical Properties of Soil

The physical properties of the soil affect directly or indirectly the soil-tool interaction. Soil samples from different parts of experimental plots was collected to determine the status of the soil. soil samples were collected randomly at depths of between 10-20 cm, using a soil auger. This was to determine the bulk density, moisture content, and soil texture. The composite soil samples were put in polyethylene bags and taken to the soil laboratory of the research center for analysis.

Table 1. Unit draft of plough (K) for different types of soil

Soil type	K, (N/cm^2)
Light soil	2.1-4.l
Medium soil	3.4-6.2
Heavy soil	5.88-9.7
Very heavy soil	8.82-14.71

Source: Sharma and Mukesh (2010)

3.3.1. Moisture content

The soil moisture content influences draft, workability, power transmission of the machine during operation, and wheel slippage. The gravimetric method (that is oven dry method) was used to determine the soil moisture content. Wet soil was weighed and put into an aluminum pan and placed inside an oven at 105°C. The moisture content of the soil was calculated by formula. (Mohsenin, 1979). The percentage of water in a soil sample was calculated as follows.

$$\text{Soil moisture content} = \frac{M_i - M_f}{M_i} \text{x } 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.0)$$

Where: M_i = weight of wet soil sample, kg

M_f = weight of oven-dry soil sample, kg

The experiment was replicated for three samples from different parts of the field and the mean value was calculated.

3.3.2. Bulk density

Bulk density of the soil is a measure of compaction of the soil condition which influences the machine components. It was calculated the formula reported by (USDA-NRCS, 1999). The bulk density of the soil was calculated using the following formula.

$$\text{Bulk density } = \frac{\text{dry weight of bulk sample}}{\text{volume of soil core}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.1)$$

3.3.3. pH value of the soil

pH value is the measure of the hydrogen ion concentration in the soil to determine the alkalinity or acidity of the soil. A pH value of 7 indicates a neutral condition. Value of 7.5 to 8 indicates the presence of carbonates of calcium and magnesium. Value above 8.5 indicates the presence of exchangeable sodium in the soil medium. The experiment was taken from two depths with three samples taken from different locations of the experimental plot and the mean value was calculated. It was determined by using a pH meter.

3.3.4. EC value of the soil

Electrical conductivity (EC) of the soil is the measure of concentration of soluble salts. The extent of soil salinity was measured using a conductivity meter and indicated as ds/m. The experiment was taken from two depths with three samples taken from different locations of the experimental plot and the mean value was calculated.

3.3.5. Soil strength

Direct shear test was conducted using vane shear-meter apparatus. Experiment was replicated with three samples from different experimental plot and the mean value was calculated.

3.3.6. Soil texture

Percentage of different size soil particles in a given oven dried soil sample is found out by hydrometer analysis of ASTM type 152H. By this method after 40 second all sand-sized particles (0.02 mm and larger) settle out of the suspension and after 2 hour, particles larger than clay (0.002 mm) settle out of the suspension. Sieves size of 2 mm, 1 mm, 600, 425, 300, 212, 150 and 75 microns were used respectively.

3.4. Experimental Materials

3.4.1. Material description of broad-bed maker

After using the mechanical properties of the mild steel for analyzing the stress, bending due to draft, material failures due to load by using standard mechanical design software's mild steel was used throughout the production process of the prototype due to its abundance in the workshop.

In the construction of an implement, it is advisable to eliminate as many castings as possible and to use pressed, stamped and tabular steel. This results in reduction of weight and cost of an implement in addition to retaining the required strength, and durability in case of repairs.

Generally, choice of the material was on the basis of following factors.

- Cost of material and easy availability.
- Easy handling and processing.
- Suitability of material to satisfy the need.
- Reliability while it is in operation.

3.4.2. Selection of material

The choice of the material was firstly governed by the requirements, concerning the function, stressing and the life of the component.

- **Mild Steel**

Mild steel (MS) also known as low-carbon steel, has a relatively low tensile strength, but it is cheap and easy to form (ASTM A29). Frame and all the machine components were fabricated from the mild steel. Mild steel is used as, it is able to withstand with the loads that will occur against machine elements.

Table 2. Material properties of AISI 1020 mild steel (MS)

Material Properties	Values	Units
Young Modulus (Modulus of elasticity)	205	GPa
Tensile strength	420	MPa
Yield strength	350	MPa
Shear modulus (typical for steel)	80	GPa
Poisson Ratio	0.27	-
Density	7200	kg/m3
Machinability (based on AISI 1212 steel. as 100 machinability)	65	-
Allowable shear stress	525	MPa

Source: ASTM A29/A29M Standard.

- **Bolts**

The bolts were chosen based on the specification, which covers the requirements for various types of quenched and tempered steel bolts in nominal thread diameters M16 to M36 inclusive, commonly referred to as "high-strength structural bolts," intended for use in structural joints that are equivalent to those made using ASTM A 325M or A490 Bolts (ASTM A325M-00).

Table 3. Materials used for the construction of prototype BBM

No	Components	Material
1	Bed leveller	MS sheet
2	Frame	MS
3	Nuts and bolts	Hardened steel
4	Furrow marker	MS
5	Ridger	High carbon steel
6	Shank/Tyne	High carbon steel
7	Three-point hitch	MS

Table 4. Workshop machines used for the construction of prototype

No	Type of machine	Application
1	Welding machine	For welding parts together
2	Grinder	To face the welding parts
3	Drilling machine	Making a hole in different parts
4	Lathe machine	For boring the hole
5	Hack sow	For cutting parts
6	Bending machine	For twisting part
7	Steel scale	For measuring linear distance
8	Centre punch	Hole marking
9	Hammer	To strike the steel
10	Chisel	Cutting
12	Cutter machine	Cutting sheet metal
13	Wrench	Tightening nut and bolt
14	Hand grinder (cut-off)	Grinding metal sheet
15	Flat file	Smooth rough edges

3.4.3. Tractor size categorization

Table 5. Tractor size category

Equipment type / Farm tractors	Power range
Small	<60 kW (80 hp)
Medium	60 - 112 kW (80-150 hp)
Large	>112 kW (150 hp)

Source: ASAE D497.4 MAR2011 (R2020)

3.4.4. Operation principle

The prototype was operated with a small to medium horsepower tractor (Appendix III) through the three-point hitch linkages. The frame is vertically connected to the shanks/tyne on one side, and the hitches on the other by bolts and nuts. By raising and lowering the hydraulic lever, the plow bottoms were easily be engaged to the soil. The depth was adjusted by setting the tractor's hydraulic systems. The wings of the plow were adjusted as per the furrow width requirements and the plow bottoms were connected to the frame, with bolts and nuts fastened on plates.

Figure 6. Working principles of the developed prototype

3.5. Methods

The methods have the following procedures.

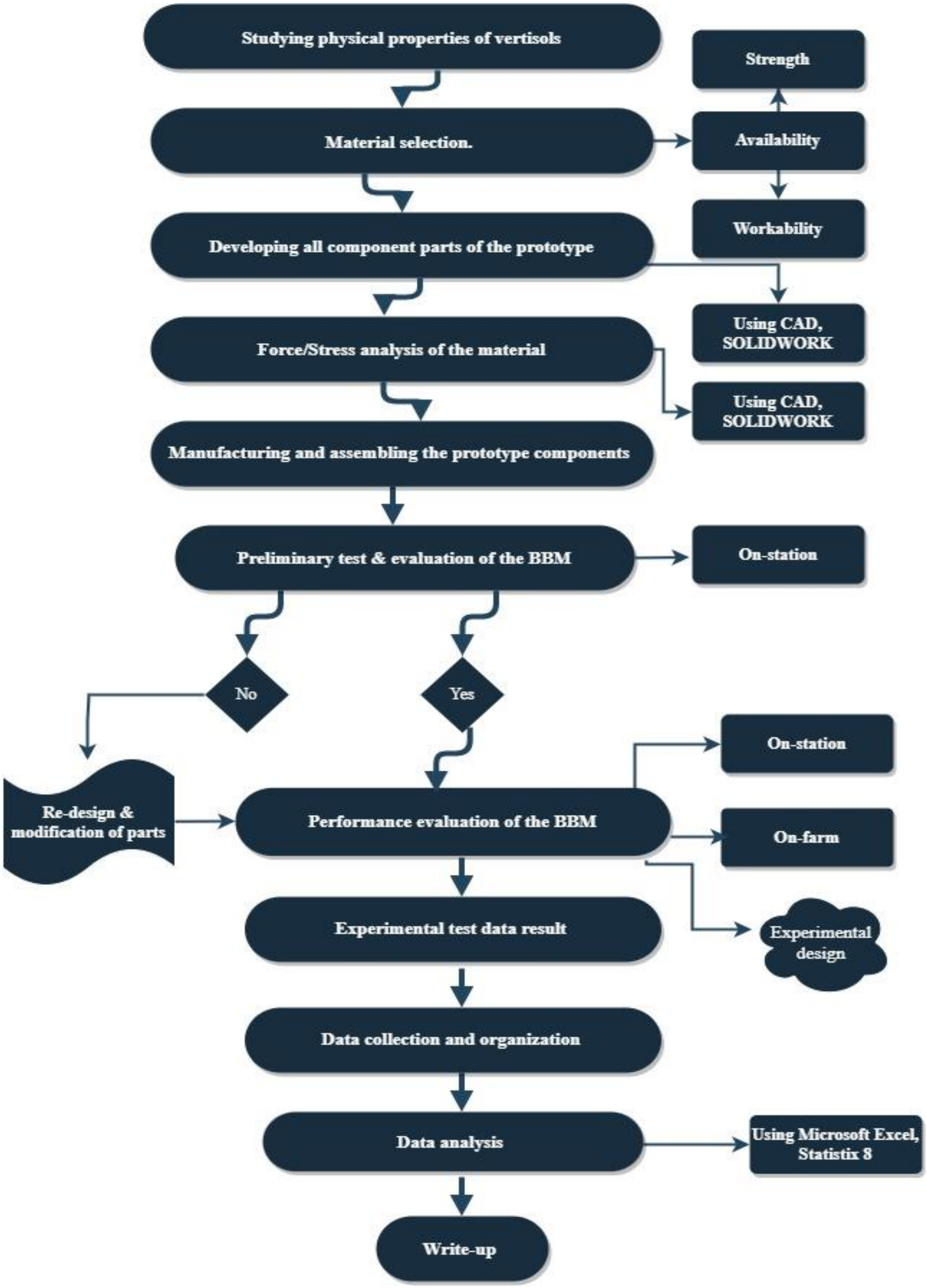


Figure 7. Procedures of method

3.6. Design Parts of Broad-bed Maker

A. Functional components of the machine

This machine consists of the following functional components.

- Main frame, and Hitching unit
- Furrow openers
- Ridger and Tyne's

It was consisted of two furrow openers (ridger) attach to the shank with mainframe and three-point linkage. During the working position, the furrow opener was attached at the frame with the help of a tyne form the soil and the bed leveler levels the land and broad bed is prepared.

B. Selection/design of attachment for broad-bed maker

Draw bar horse power. (DBHP) = 60 % of BHP. The available horsepower of a tractor is 100 hp

Therefore, we know, tractor drawbar horse power can be calculated from the equation below:

$$\text{DBHP} = 60\% \text{ of BHP} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.2)$$

Therefore, DBHP = 100 hp x 0.6 = 60 hp

The tractor drawbar horse power (DBHP), draught available (Df) was calculated by equation (3.3) (Sharma and Mukesh, 2010)

$$\text{DBHP} = \frac{D_f \text{ x V}}{270} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.3)$$

Where: D_f = draft force, (kg)

V = speed, (km/hr)

Generally, the speed of bedding was done on the range 3 - 4 km/hr (ASABE, 2011) (R2020).

Let the forward speed of bed-maker be 3 km/hr.

Putting the values in the equation (3.3),

Brake Horse Power (BHP) of tractor = 100 hp

Drawbar Horse Power (DBHP) = 60% of BHP = 0.60 x 100 = 60 hp

$$\text{Draft available for bed} - \text{making (pull)} = \frac{60 \text{ hp x } 270}{3\,\frac{\text{km}}{\text{hr}}} = 5{,}400 \text{ kgf}$$

C. Width of implement

The minimum working width of implement to plant six seeds in the bed was calculated using the formula.

$$\text{Width of the BBM} = N_s \text{ x S} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (3.4)$$

Where: Ns-number of seed placed across the bed, S-space between the seeds. Let Ns be 6 and distance between them is 20 cm, and to prevent the seed falling into furrows some space was given.

Therefore, working width of the BBM $= 6 \text{ x } 20 = 120$ cm

3.6.1. Design of mainframe

The material of the mainframe was selected based on achieving a reasonable weight and required strength and reliability and availability of the material in the market. Soil cutting units, furrow openers, ridgers, hitching unit were mounted on the main frame. The frame has provision for attachment of replaceable parts such as ridger and furrow opener.

(i) Size of toolbar frame

The size of toolbar of the machine is decided based on the facts that:

a) This can be used as a 2-bottom ridger bed maker for bed planting.
b) In the bed-maker, two ridger bottoms was attached at a spacing of 120 cm and two furrow openers was fitted to the rear toolbar as per the spacing requirements of the crop sown (considering using broadcasting or planter/ drilling for tef and wheat crop the bed can hold up to 6 seed across the bed and the spacing between the seed is 20 cm (Gemechu et al., 2021; Atlaw et al., 2015).
c) Both the toolbars are joined together with the help of rectangular hollow section (RHS) at a distance of 600 mm to make it a rectangular frame.
d) The furrow openers are attached to the toolbar with the help of clamps.

The frame for the BBM consisted of a rectangular base of 1500 x 600 mm size made of RHS of 70 x 50 x 5 mm and three-point hitch of standard size was extended out from main frame. Figure 8 shows an isometric view of the frame, and figure 12 shows a detailed view of main frame with three-point linkage.

The frame was subjected to torsion and bending moment due to the fixing of tines on the frame. The design should be based on the stresses produced on the front of the frame (Lal and Datta, 2011).

Length of toolbar = tyne accommodation space + spacing between the furrow opener

= 30cm + 120cm = 150cm

To estimate the total draft equation (3.5) is used it was given by (Sharma and Mukesh, 2010)

$$\text{Total draft(Df)} = \text{k x n x a x b} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \quad (3.5)$$

Where: k: unit draft (kg/cm^2), and n: number of furrow opener.

a: depth of furrow (cm), and b: width of furrow (cm).

Assumption was made for the design of implement frame by taking the maximum values.

Let k=0.75 kg/cm^2, n=2, a=25 cm, and b=35 cm

Df = 0.75 x 25 x 35 x 2 = 1,312.5 kg-f

Therefore, Df = 1,312.5 kg-f

Total torque on the back of frame (T) = 2 x 1,312.5 x 75 = 196,875 kg-cm.

In addition to the torque, bending will also produce on frame.

Rx = (1,312.5 kg x 2) ÷ 2 = 1,312.5 kg

Ballasting for attaining the needed depth = 50 kg (max) and assumed to act at the center of the tollbar. Hence, Maximum bending moment on the center was given by:

M = (1,312.5 kg x 75 cm) + (50 kg x 75 cm) – (1,312.5 kg x 75 cm)

M = 3,750kg-cm

So, Equivalent toque (T) = M + T

T = 3,750 kg-cm + 196,875 kg-cm

T = 200,625 kg-cm

The maximum shear stress developed at the center of the tollbar was obtained by the following relationship.

$$S_x = \frac{T}{Z} \quad \ldots \ldots \ldots (3.6)$$

Where: Sx = Shear stress at any section

T = Total torque developed = 200,625 kg-cm

Z = Section modulus = ($\frac{I}{Y}$) and

I = Moment of inertia of frame (RHS)

$$I = \frac{(a^4 + b^4)}{12} \quad \ldots \ldots \ldots (3.7)$$

Y = distance of the section from natural axis;

$$Y = \frac{a}{2} \quad \ldots \ldots \ldots (3.8)$$

Now, rectangular hollow section (RHS) was taken for the design of frame assuming section was 70 x 50 x 5 mm.

So, a = 70 mm and b = 50 mm

Therefore, from equation (3.7) and (3.8) moment of inertia of frame and distance was:

$$I = \frac{(70^4 - 50^4)}{12} = 1{,}480{,}000 \text{ mm}^4$$

Y = a/2 = 70/2 = 35 mm

Section modulus (Z) = $\frac{I}{Y}$ = 42,285.71 mm^3

The maximum shear stress developed at the center of tollbar was obtained by the following relationship (Khurmi and Gupta, 2005).

$$S_x = \frac{200{,}625 \text{ kgcm}}{42.285 \text{ cm}^3} = 4{,}744.59 \text{ kgcm}^{-2}$$

The allowable shear stress for MS (mild steel) rectangular section was 525 MPa or 5,353.425 kg/cm^2 (ASTM A29/A29M-14:2018), which was higher than the designed stress. Therefore, the material taken for the frame was of size 70 mm x 50 mm rectangular section with having a thickness of the material of 5 mm was used for the construction of the frame broad-bed maker. A three-point category-II hitch was welded on the top of the frame to mount the unit to the tractor.

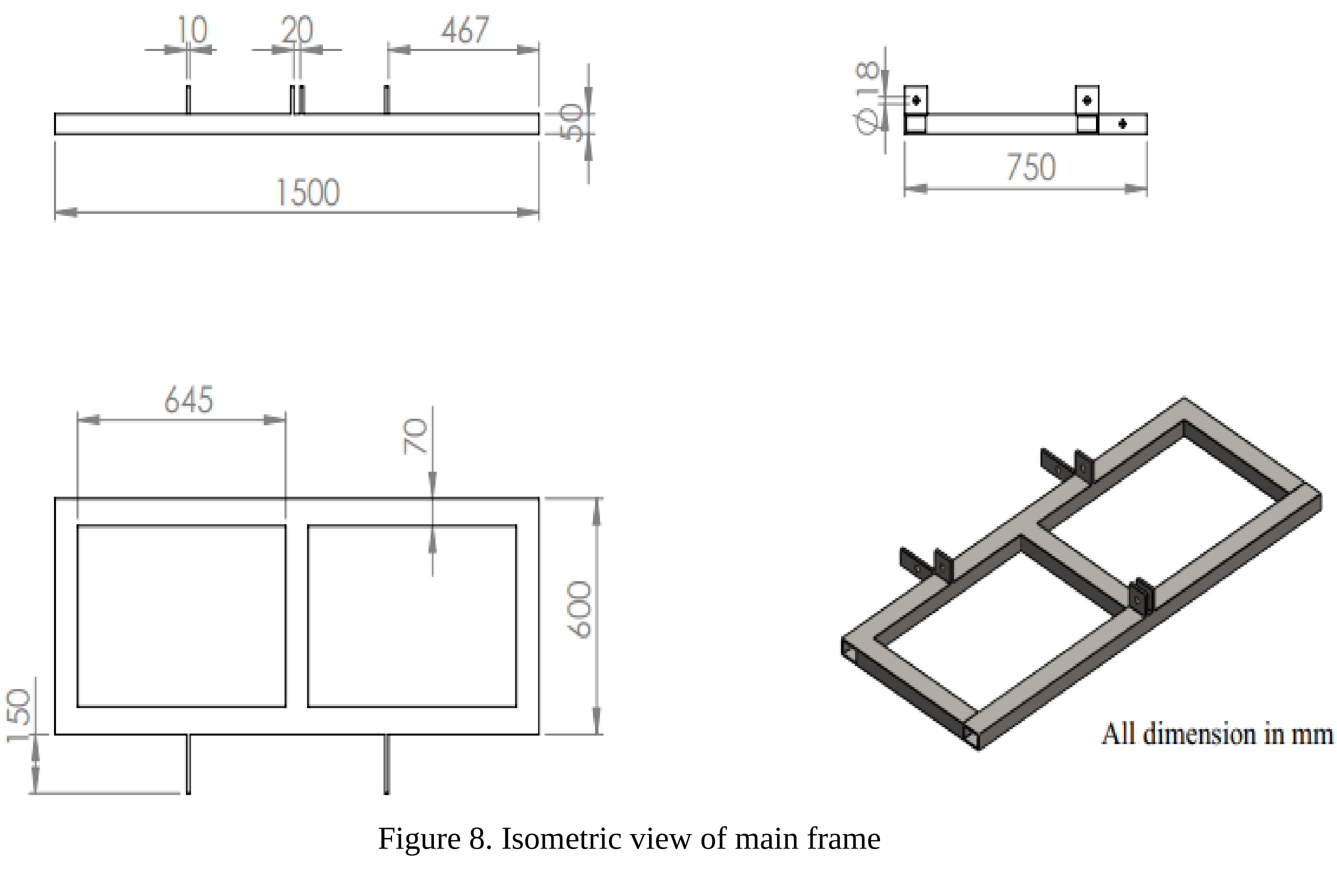


Figure 8. Isometric view of main frame

Meshing of frame: Figure 9. Shows meshing of frame by using SOLIDWORKS software 2021. To generate the mesh model of the frame, with curvature-based mesh element size is default and soothing is fine in the mesh program.

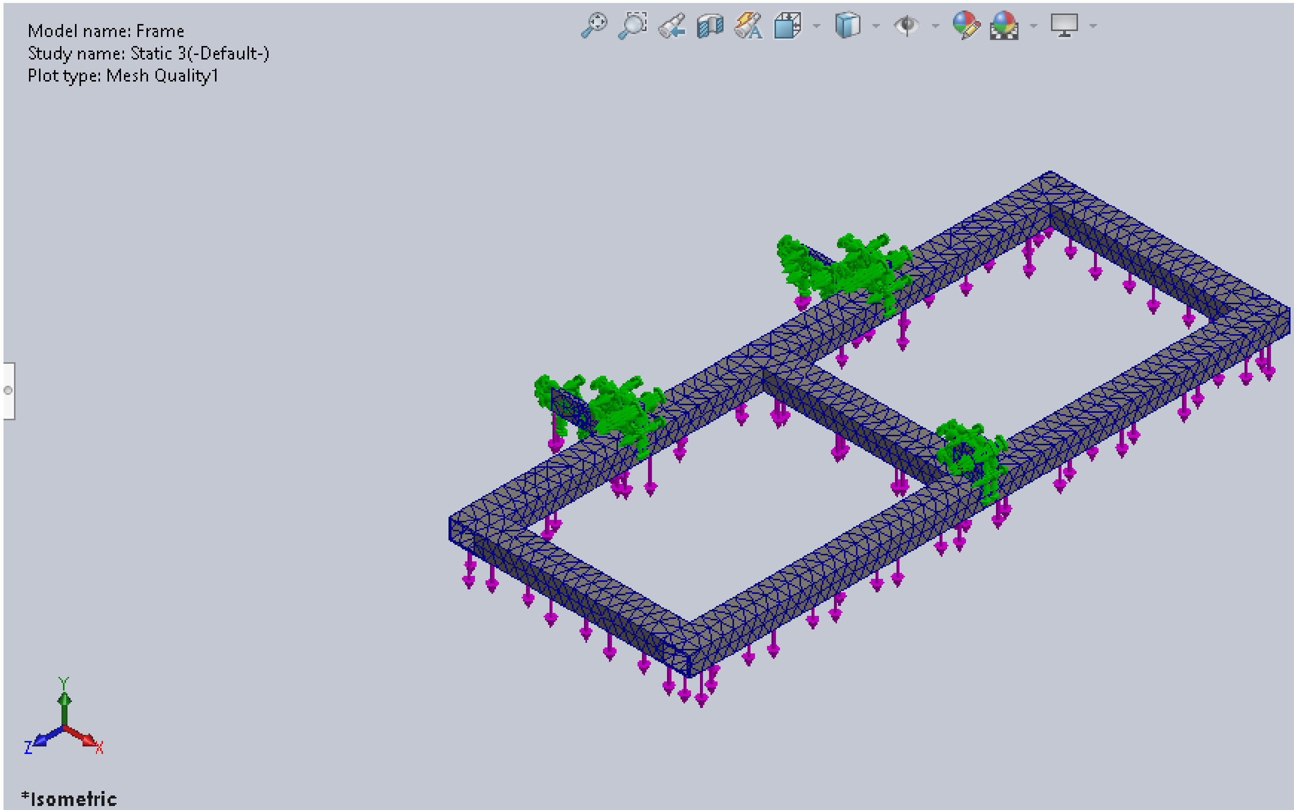


Figure 9. Meshing for frame

Figure 10 shows the von-Mises stress affected on the frame for AISI 1020 steel. It can be noticed that the maximum stress is generated at the frame tollbar supports the tyne is 81.3 MPa, which is below the yielding stress of the AISI 1020 steel.

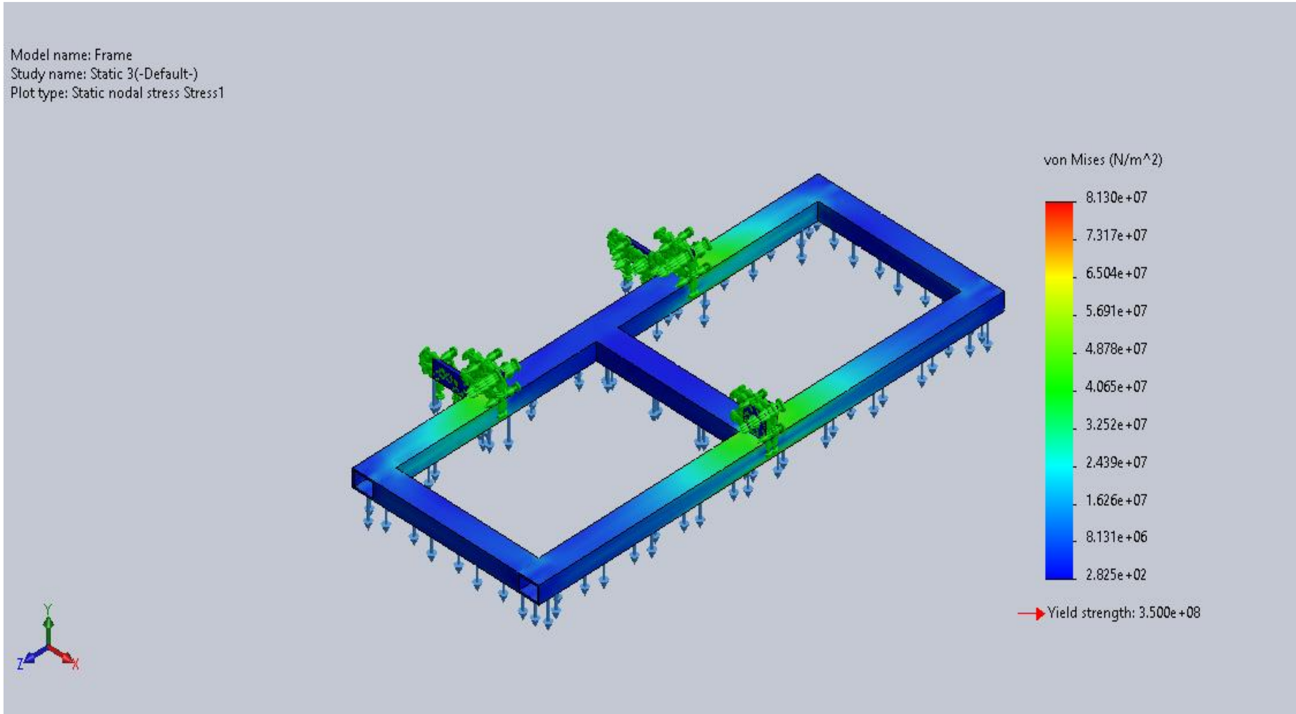


Figure 10. Von-Mises/Simulation result of stress due to draft on frame

Figure 11 shows the analysis of the equivalent elastic strain on frame for AISI 1020 steel. The selected maximum elastic strain is 2.725 x10^{-4}.

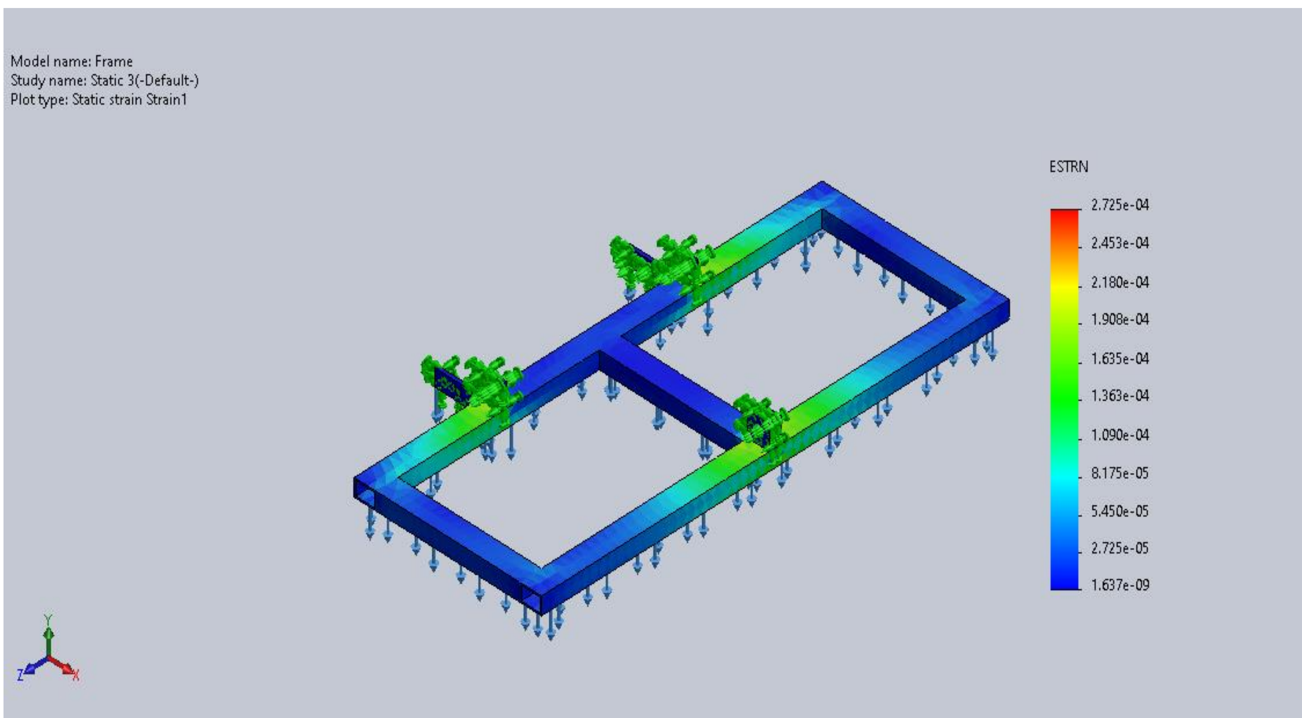


Figure 11. Simulation result of equivalent elastic strain due to draft on frame

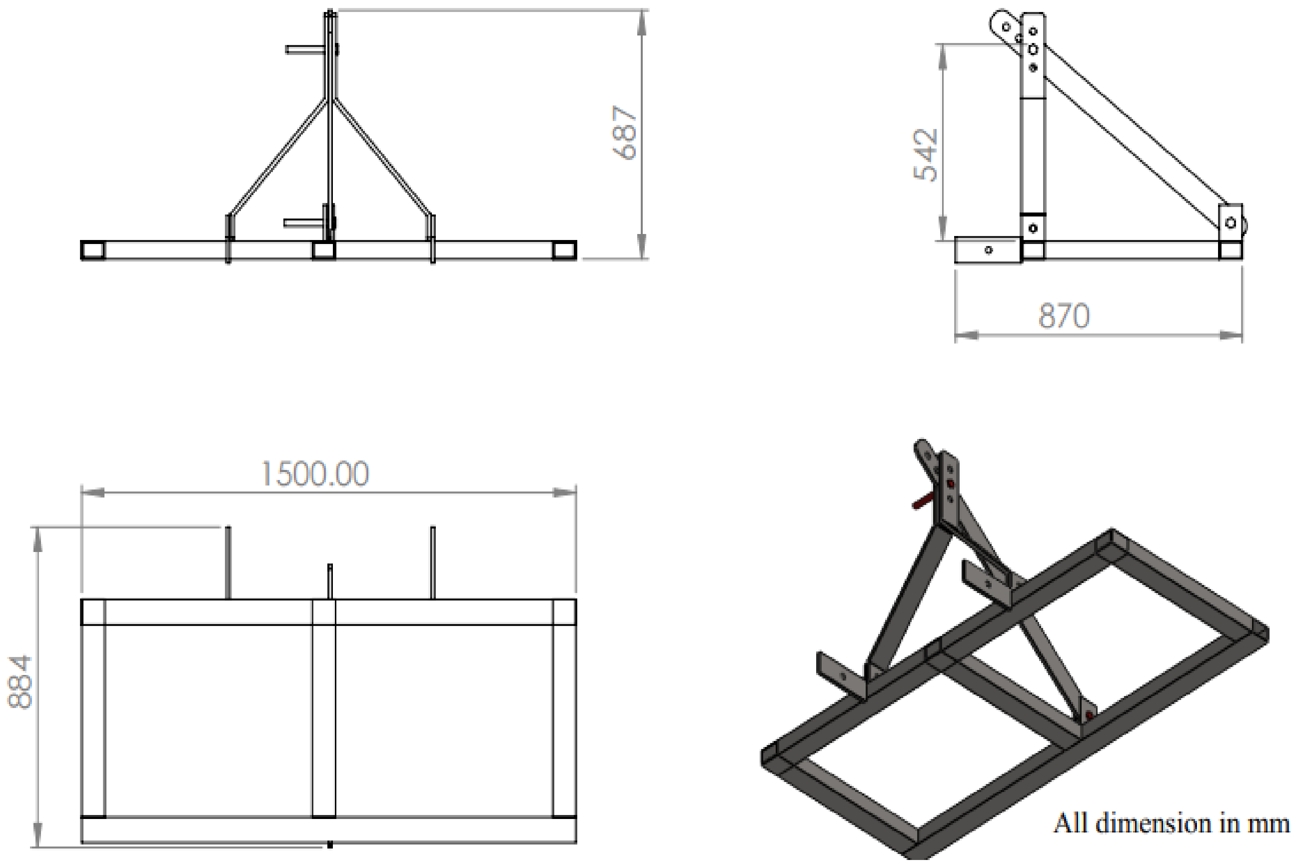


Figure 12. Shows a detailed view of main frame with three-point linkage

3.6.2. Design of furrow openers

The furrow openers of a bed maker device are the final modifier of the soil environment in a seedbed. Hence, they are one of the most important components of a broad-bed maker.

Verma and Gupta (2016), state the shoe type furrow opener was designed to work the machine in poorly prepared land. In this study the shoe type furrow opener was taken in the development of broad-bed making. The main aim was to open the furrow up to 20 cm depth and 30 cm width. The furrow opener selected was made up of 40 mm thick mild steel material. It was a dull rectangular shape having one of its tips parallel to the direction of motion.

3.6.2.1. Ridger / Plow bottoms

Two ridger are provided on both side of the bed maker. It consists of two wings, tyne, width adjusting braces. Holes are provided on the MS flat welded on tyne for adjusting the contact angle of ridger. Curved shape and the maximum angle of setting of the wing is 40° at maximum opening of wings this was selected because of the ability of the furrow opener that produce wider furrow profile and this was important for leaching of more water from the field. The selected shear rake angle was 30^o. The furrow depth that corresponds to the maximum rake angle. This trend was caused by raising the share rake angle, which increased share penetration into the soil. The curved wing's edge of the bed and furrow depth were both higher than the straight wings. This might be due to the straight wings shortly after they developed collapsing the soil inside the furrows. Increasing wing angle tends to increase the furrow width due to increase the soil cross-sectional area that moves in the front of the share. These results agree with the report by (Marey, 2015).

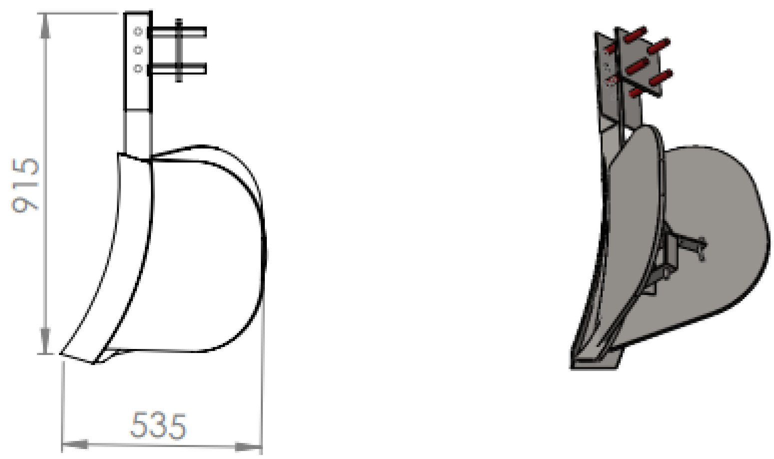


Figure 13. Schematic view of ridger

Figure 14. Size adjustment of the plough bottom

3.6.2.2. Design of tyne for furrow opener

(a) Calculation on the draft load on furrow opener tyne/shank (Df): Force exerted on the ridger tyne furrow opener of broad-bed maker is estimated by the formula given by (Sharma and Mukesh, 2010). Design of tyne of the furrow opener:

$$D_f = k \text{ x } w \text{ x } d \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (3.9)$$

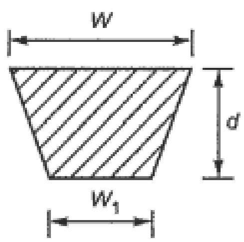
Where: Df = draft of furrow opener, kgf

k = soil resistance, kg/cm^2

w = width of furrow opener, cm

d = working depth, cm

Let the furrow opener make trapezoidal type of furrow as under:



Now, for design purpose some assumptions are made and taking the maximum value of it.

Assumptions, w = 35 cm, d = 35 cm, w_1 = 15 cm, k = 0.75 kg/cm^2

Therefore, putting values in equation 3.9,

Df = 0.75 x [(35+15)/2] x 35 = 656.25 kgf or 6,435.84 N

Now, for mild steel tynes factor of safety of 2 was used.

So, design draft of furrow opener would be;

Df x f.o.s = 656.25 kgf x 2 = 1,312.5 kgf or 12,871.68 N

Maximum bending load on tip of each furrower = 656.25kgf or 6,435.84 N

Height of shank of furrower = 0.6 m

Therefore, the maximum bending moment (M) for a cantilever length of 0.6 m

M = 6,435.84 N x 0.6 m = 393.75 N-m

(b) To determine the bending moment in the furrow opener tyne based on findings of (Sharma and Mukesh, 2010) by taking radius of curvature (R), R=120 or by calculating assumed variables as follows.

Let, h = 140 mm, l = 110 mm and α =25° and putting these values in the following equation,

$$R = \frac{(h - l\sin\alpha)}{\cos\alpha} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (3.10)$$

Where: h = height of tyne /shank from its tip to the bent portion, mm

α = rake angle, degrees and l = length of tyne from the tip of shovel to the frame, mm

Therefore, from equation (3.10), R = 103.2 mm which is less than 120 mm.

The bar was considered as a simply supported beam or cantilever beam of 600 mm size fixed to the frame at one end. To estimate the maximum bending moment (M) equation (3.11) was used (Sharma and Mukesh, 2010).

$$M = \text{Design draft x Beam span} \dots \dots (3.11)$$

$= 656.25$ kgf x 60 cm

$= 39{,}375$ kg-cm

Now, section modulus of the tyne (Z) is calculated as under:

$$\sigma_b = \frac{MC}{I} = \frac{M}{Z}\left(\text{as } Z = \frac{I}{C}\right) \dots \dots (3.12)$$

Where: σ_b = bending stress in tyne kg/cm^2. We can take bending stress in MS flat as 1120 kg/cm^2

M = bending moment in tyne kg-cm.

C = distance from the neutral axis to the point at which stress is calculated, cm

I = moment of inertia of rectangular section, cm^4

Z = section modulus of the tyne.

Also, For rectangular sections,

$$Z = \frac{tb^2}{6} \dots \dots (3.13)$$

The ratio between the thickness to width (t:b) = 1:3 to 1:4 can be taken (Sharma and Mukesh, 2010). So, t:b = 1:3

Therefore, b = 3 t

From equation (3.13), section modulus of the tyne was calculated as follows:

$$Z = \frac{9t^3}{6}$$

Also, $Z = \frac{M}{\sigma_b}$ = 39,375 kg-cm / 1120 kg/cm^2 = 35.15cm

or, 35.15 = $1.5t^3$

t^3 = 23.43

t =2.86 cm or 28 mm

b =23 x 3.0 = 69 mm.

Therefore, cross-section of the tyne is 28 x 69 mm. or, we may take MS flat of 30 x 70 mm for the tyne of broad-bed maker. Tynes are made up of MS flat of thickness 30 mm. The length of tynes 690 mm and width 70 mm. One MS flat of size 155 mm x 155 mm x 4 mm and two MS angle of size 260 mm x 70 mm x 5 mm was connected at top side for clamp attachment with four 14 mm diameter holes. Total two numbers of tynes are attached to the frame with the help of clamps and nuts. Clamps provided so that spacing between tynes can be adjusted.

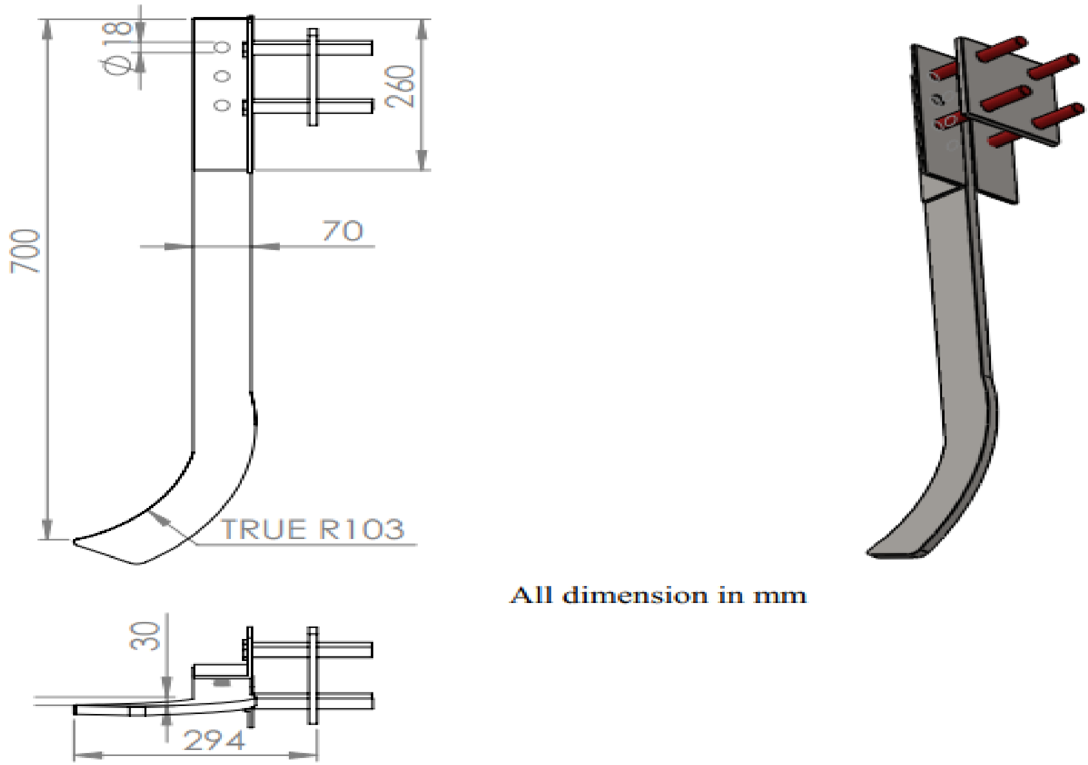


Figure 15. Schematic view of tyne

The tyne of the furrow opener was exposed first of all to bending in consequence of soil resistance. The soil resistance (k) is horizontal and it was acting in the axis of symmetry of shoe. The soil resistance was assumed to be 3 to 5 times higher than actual average soil resistance offered by the particular soil or for heavy clay it is assumed to be 0.75 kg/cm^2 (Sharma and Mukesh, 2010). The value of the actual average soil resistance is obtained by the formula given be (Varshney et al., 2004)

$$F = a \times Ww \times P \quad \ldots\ldots (3.14)$$

Where: a = Effective working depth of tyne = 350 mm

Ww = Effective working width of tyne = 350 mm

P = Specific soil resistance for heavy clay soil = 0.75 kg/cm^2

Therefore,

F = 350 mm x 200 mm x 0.0075 kg/mm^2 = 525 kg

The soil resistance was assumed to be 3 to 5 times higher than actual average soil resistance (F)

Draft at the tip of tyne (Dt) = 525 x 3 = 1575 kg

Stress (σ), causing the tyne to bend was calculated by the formula given be (Varshney et al., 2004)

$$\sigma = 6D_t \frac{H_1 + \alpha}{t \text{ x } h^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.15)$$

Where: D_t = Draft at the tip of tyne, kg

H_1 = Length of tyne, cm

α = Effective working depth of tine, cm

t = Thickness of the tyne, cm

h = Width of tyne, cm

Therefore,

$$\sigma = 6 \text{ x } 1575 \text{ kg} \frac{70 \text{ cm} + 20 \text{ cm}}{3 \text{ x } 7^2} = 5785.71 \text{ kg/cm}^2$$

Now, Torsional stress (τ) is calculated by the formula given be (Varshney, et al., 2004):

$$\tau = \frac{9D_t \left(\frac{W_w}{4}\right)}{2h^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.15)$$

$$\tau = 9 \text{ x } 1575 \text{ kg } \frac{\left(\frac{20}{4}\right)}{2 \text{ x } (7^2)} = 723.21 \text{ kg/mm}^2$$

Then, the reduced stress was calculated as:

$$\delta = \sqrt{\sigma^2 + \tau^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.16)$$

Where: δ = Reduced stress, kg/cm^2

σ = Stress, kg/cm^2

τ = Torsional stress, kg/cm^2

$$\delta = \sqrt{5785.71^2 + 723.21^2} = 5{,}830.73 \text{ kg/cm}^2$$

Factor of safety was taken 3 times more than that of the actual stress. The allowable stress of mild steel is between (8,157.6 – 8,565.48 kg/cm^2) or 800-840 MPa which was more than the designed stress 5,830.73 kg/cm^2. Hence, mild steel (AISI 1020) had been taken for the machine.

The BBM was developed for making one bed in one pass, and two furrows. Thus, two tine was required for making one bed in one pass. The draft requirement experience by the tyne of bed maker is obtained from (equation 3.9) 656.25 kgf or 6,435.84 N. Therefore, total draft exerted by each tine of bed maker is 328.1kgf. The CAD drawing in the ‘SOLIDWORKS 2021 designing

Software' with dimensions of fabricated tyne is shown in figure 15. The draft of 328.1 kgf was applied on each furrow opener in the 'SOLIDWORKS 2021 Software' (figure 16).

Meshing of tyne: Figure 16 Shows meshing of tyne by using SOLIDWORKS software 2021. To generate the mesh model of the tyne, with curvature-based mesh element size is default and soothing is fine in the mesh program.

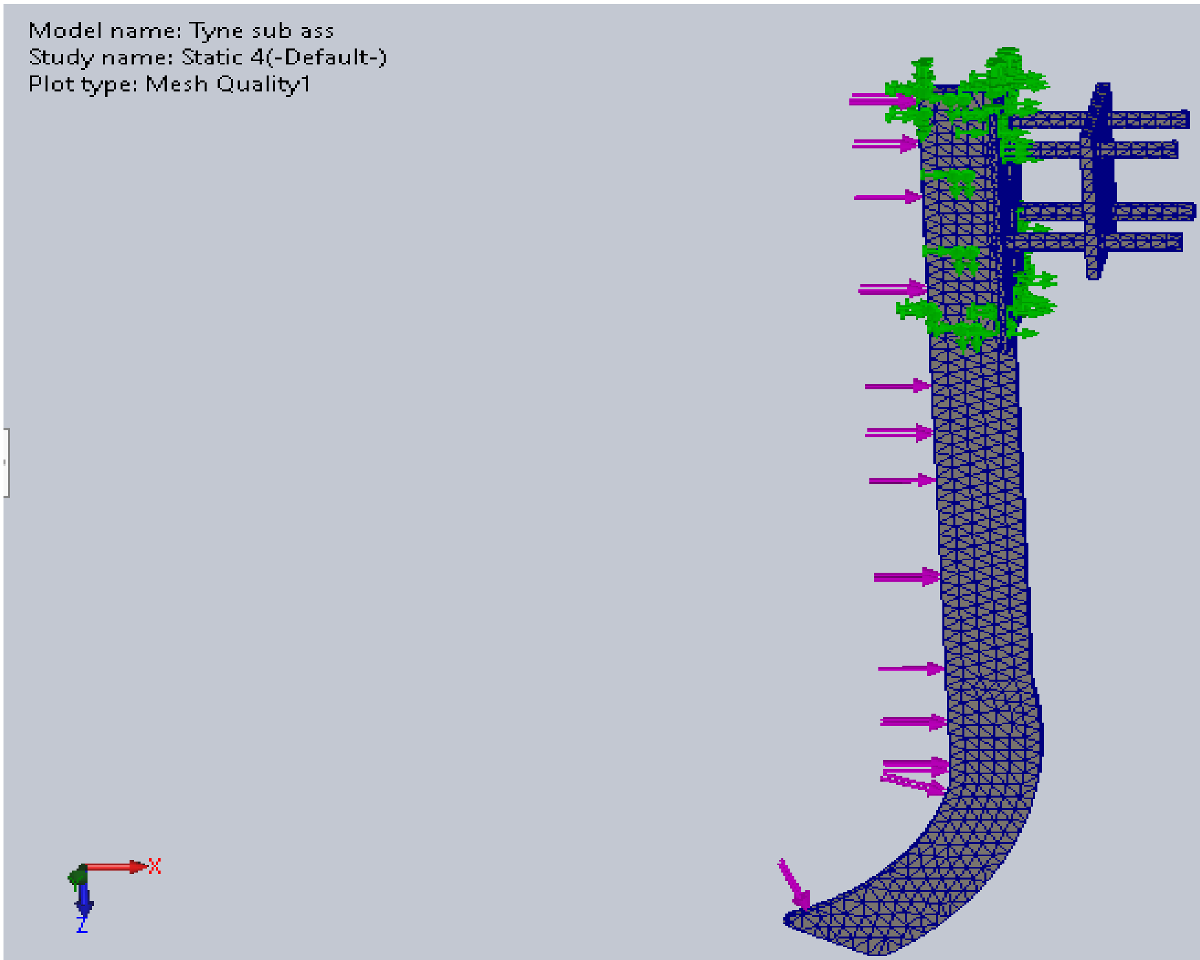


Figure 16. Meshing for tyne

Figure 17 shows the analysis of Von-Mises stress affected on the tyne for AISI 1020 steel. It can be noticed that the maximum stress is generated at the tyne is 268.5 MPa, which is below the yielding stress of the AISI 1020 steel.

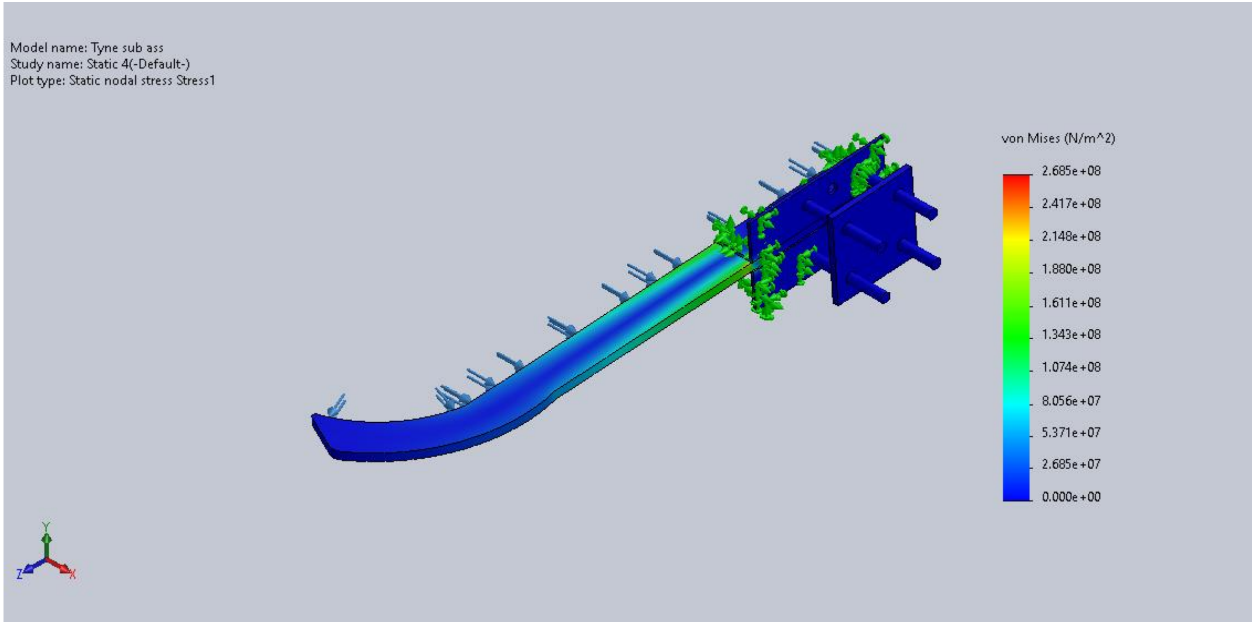


Figure 17. Simulation result of stress due to draft on tyne

Figure 18 shows the analysis of the equivalent elastic strain on tyne for AISI 1020 steel. The selected maximum elastic strain is 6.773 x10^{-4}.

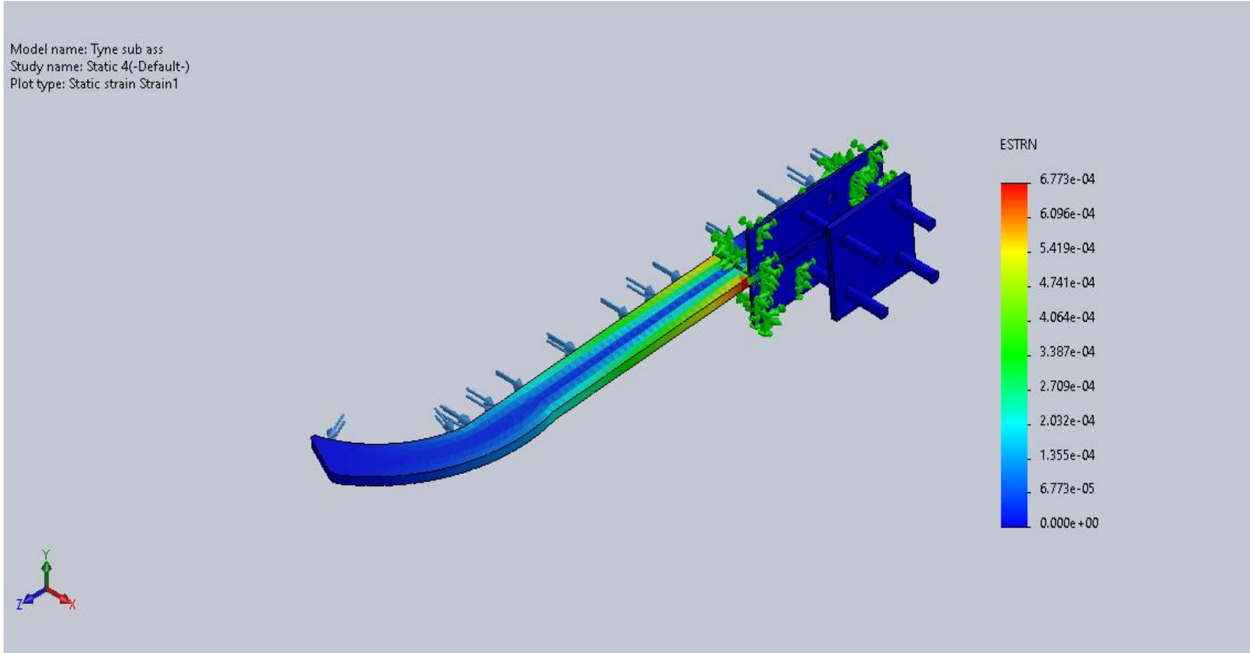


Figure 18. Simulation result of equivalent elastic strain due to draft on tyne

3.6.2.3. Hitch unit

The implement has standard three hitch points; two lower and one upper. The implement was attached to the tractor through these three hitch points with the help of link pins. The proper meshing of a tractor with a machine is an important task in implement design (Jain and Philip, 2012). Proper hitching of any kind of tractor operated implement is necessary to maintain quality of work and eliminate the power losses as per ASABE/ASAE S217.12 (ISO 730) specification for dimensions for three-point linkage of agricultural wheeled tractors.

Table 6. Three-point hitch specification

Category	Dia. of hitch pin		Mast height	Lower hitch point span	Maximum Drawbar Power, kW (hp)
	Upper link	Lower link			
1	19	22.4	400	500	15-35 (20-45)
2	25.5	28.7	683	718	30-75 (40-100)
3	31.75	37.4	825	870	60-168 (80-225)
4	45	51	920	1010	135-300 (180-400)

Source: ASAE Standard S217.12 (ISO 730)

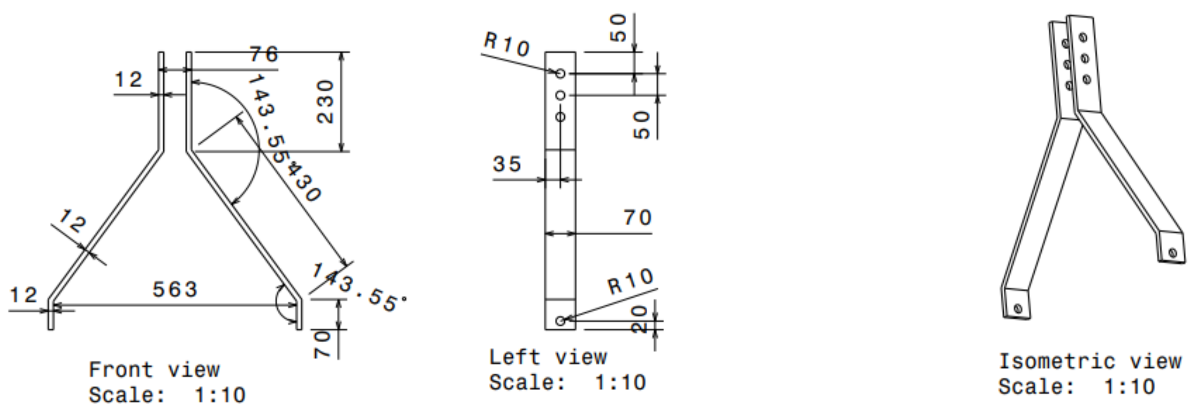


Figure 19. Schematic view of hitch unit

3.7. Development of Broad-bed Maker

The design for the tractor-operated broad-bed maker prototype was carefully considered so that it could produce the best possible results in bed making. This section explains the design and materials used to make the prototype bed maker that was developed.

3.7.1. Hitching unit and main frame

The main frame holds all components of the implement. The rectangular main frame was made up of 70 x 50 mm RHS having the dimension of 1500 x 600 mm. The counter bar of the main frame was rigidly linked with the mast as shown in the figure 20. The mast of the implement preferred was a three-point hitch of category II for small tractor having the dimensions specified in ASABE S217.12 (ISO 730) standards. The upper and lower links on the mast were made using portions of

10 mm thick and 50 mm width mild steel flats bent and linked to correlate it with hitch point standards.

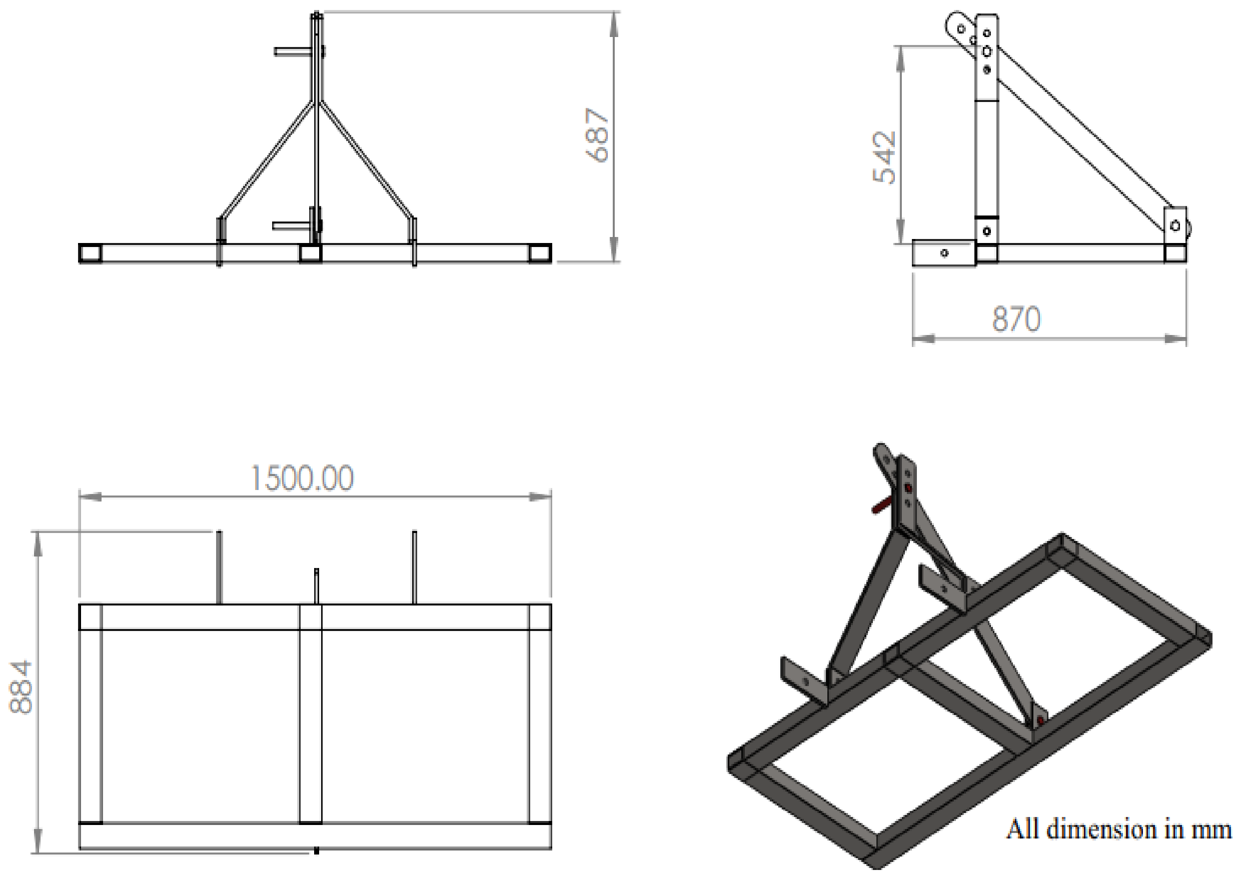
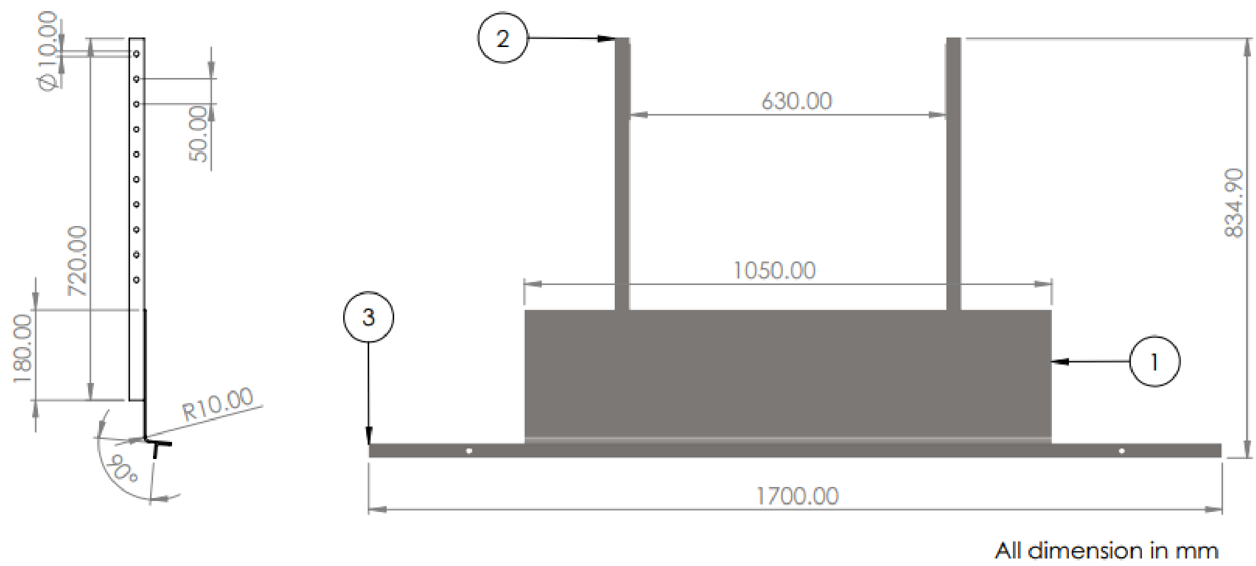


Figure 20. Isometric view of the main frame with hitching unit

3.7.2. Bed former unit

Bed formation is essential in the area where water-logging is the problem so that rectangular-shaped bed preparation device was used to level the bed area for facilitating planting in the bed. The bed former was fitted to the main-frame in the back of the furrow opener. Figure 21 shows the isometric view of the bed former unit.

Width of bed former is 1700 mm and made up of MS sheet and it fitted to the main frame by using two extension rods with the bolt to change the height of bed former and two square hollow section (SHS) was provided in between bed former to tighten with frame.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	leveler plate	MS sheet metal	1
2	leveler holder	720X30,dia10	2
3	angle iron for leveler	MS 30x30x3mm	1

Figure 21. Isometric view of bed former unit

Meshing of bed leveler: Figure 22 shows meshing of bed leveler by using SOLIDWORKS software 2021. To generate the mesh model of the bed-leveler, with curvature-based mesh element size is default and soothing is fine in the mesh program.

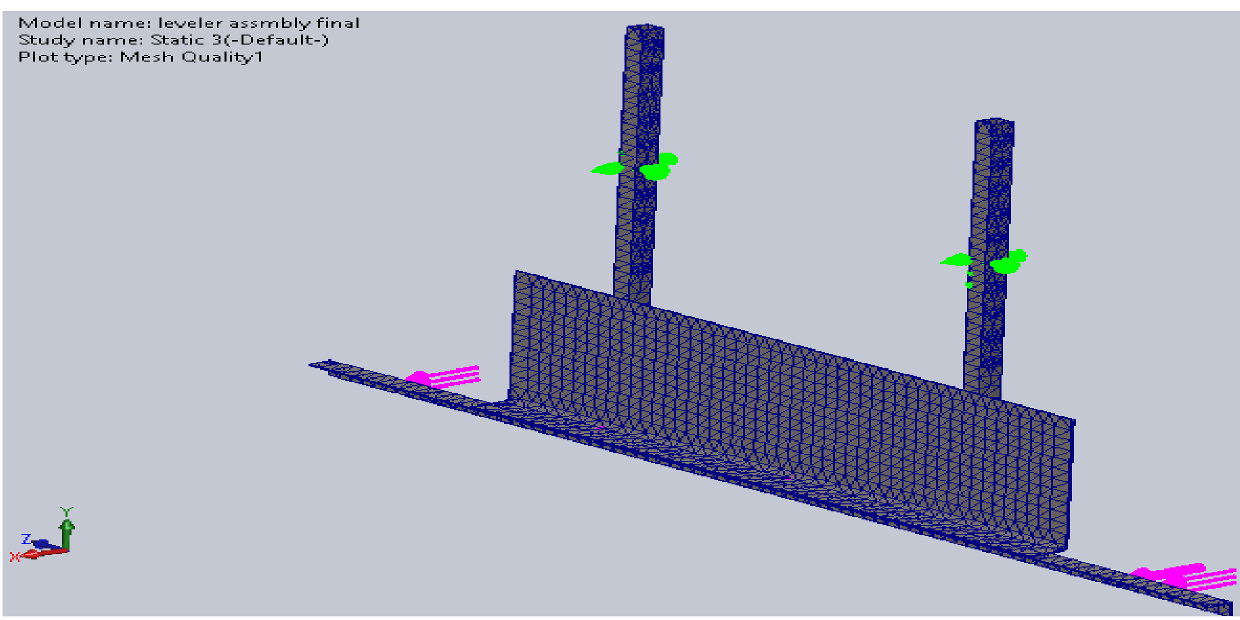


Figure 22. Meshing for bed leveler

Figure 23 shows the analysis of Von-Mises stress affected on the bed-leveler for AISI 1020 steel. It can be noticed that the maximum stress is generated at the bed-leveler is 38.83 MPa, which is below the yielding stress of the AISI 1020 steel.

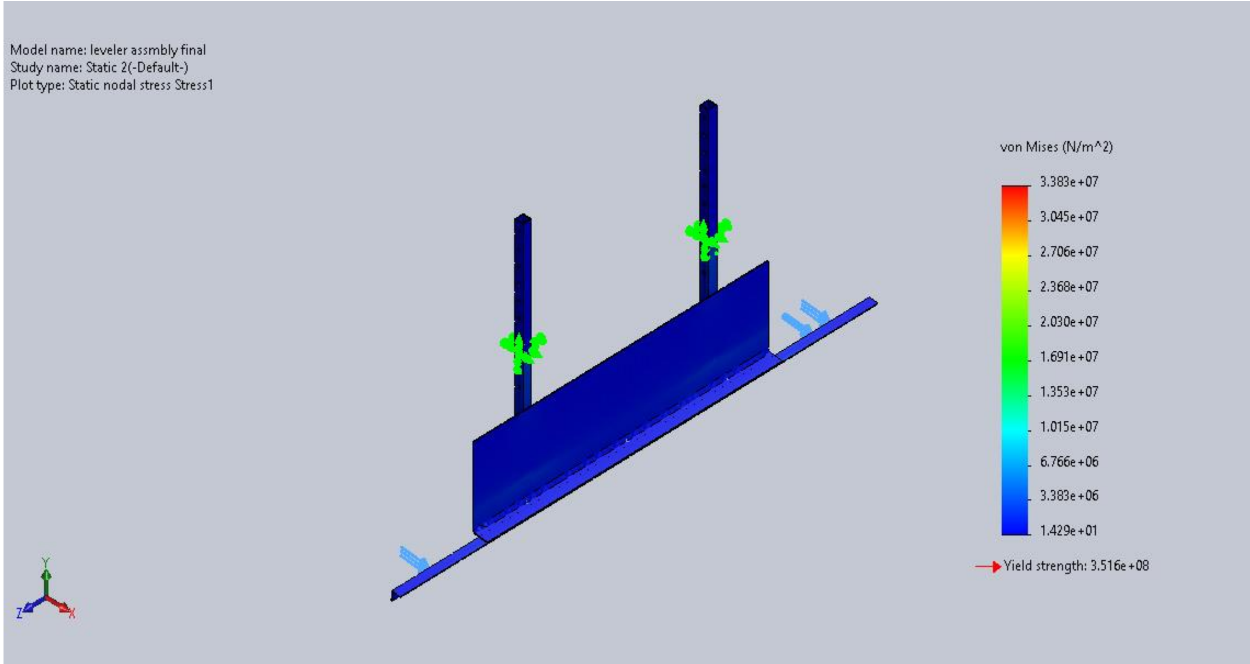


Figure 23. Simulation result of stress due to draft on bed-leveler

Figure 24 shows the analysis of the equivalent elastic strain on bed-leveler for AISI 1020 steel. The selected maximum elastic strain is 7.673 x10^{-5}.

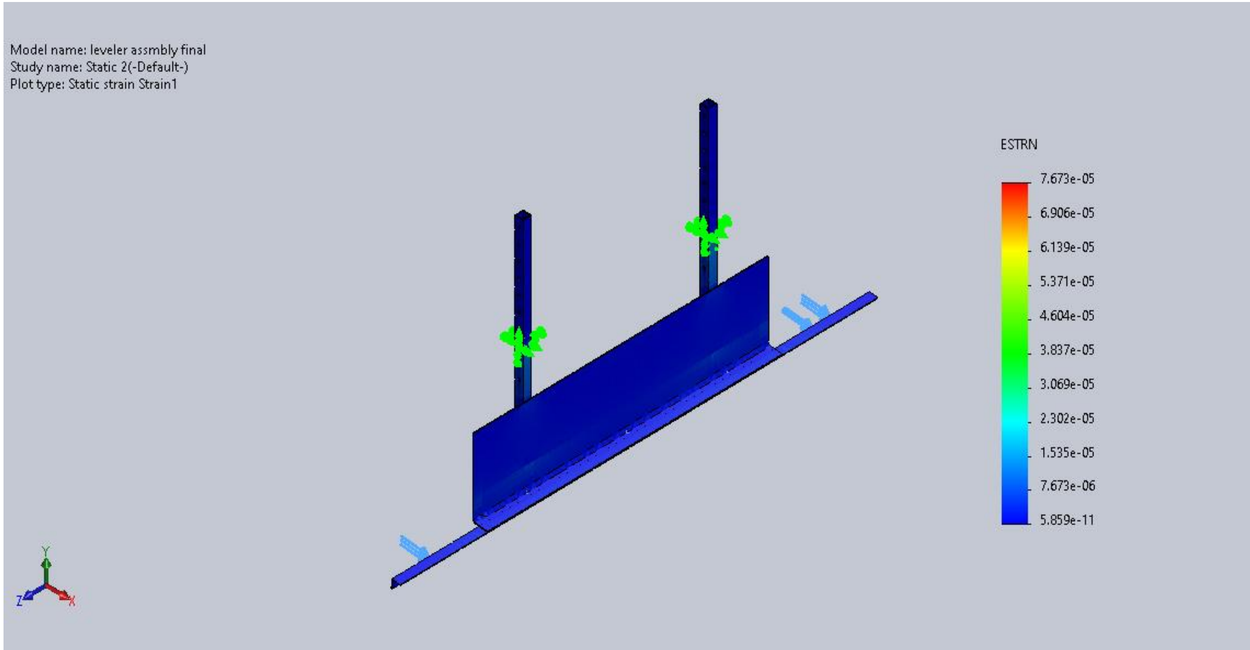
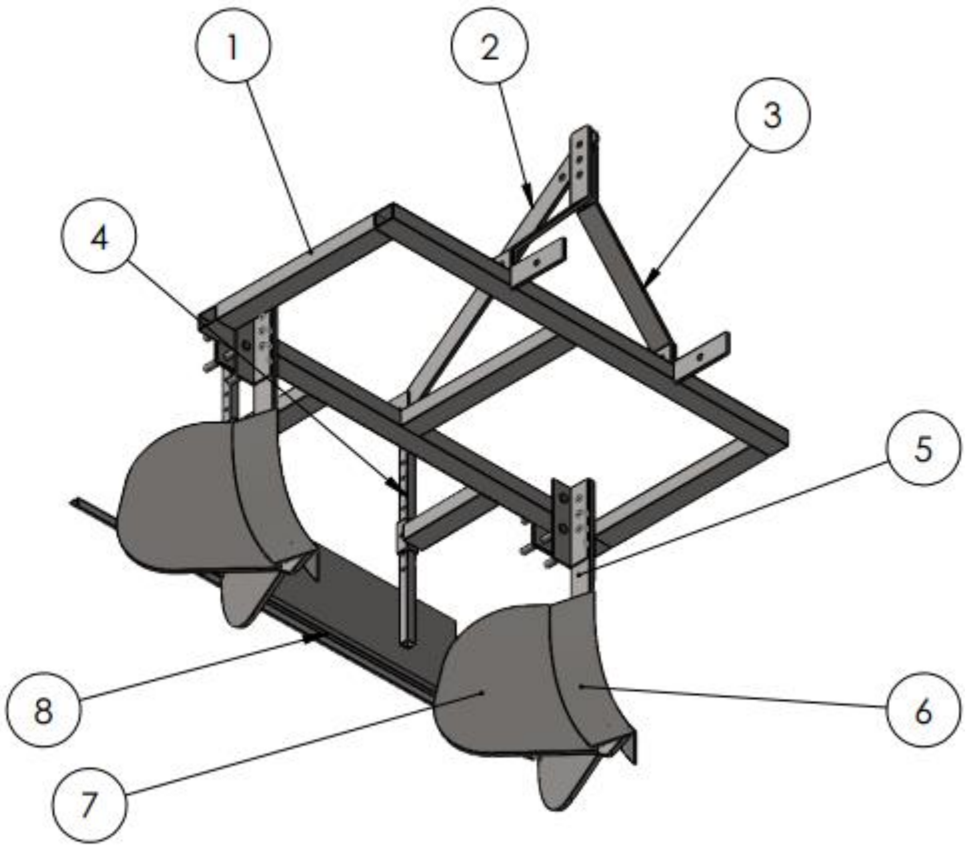


Figure 24. Simulation result of equivalent elastic strain due to draft on bed-leveler

3.8. Details of Developed Tractor Operated Broad-bed Maker

Tractor operated broad bed maker was developed in Melkassa Agricultural Research Center, Agricultural Implement Research and Improvement Center. The prototype consists of furrow openers, bed former, frame, ridger and three-point hitch. Furrow openers were used to open the furrow at the desired depth. At the back side of the frame, a ridger at the back frame toolbar and bed forming device was fixed at a distance of 30 cm in the frame toolbar. The three-point mast of category-II of standard size for the tractor was attached to main frame. The detailed view of the developed tractor operated bed maker is presented at figure 25 given below. The details of the components, their specifications and the material required are presented in table 7.



1.Main frame. 2. Top link. 3. Side link. 4. Leveler holder. 5. Tyne 6. Furrow opener. 7. Ridger wing. 8. Bed leveler.

Figure 25. Isometric view of conceptual design of the broad bed maker

Figure 26. Rear view of the developed broad bed maker

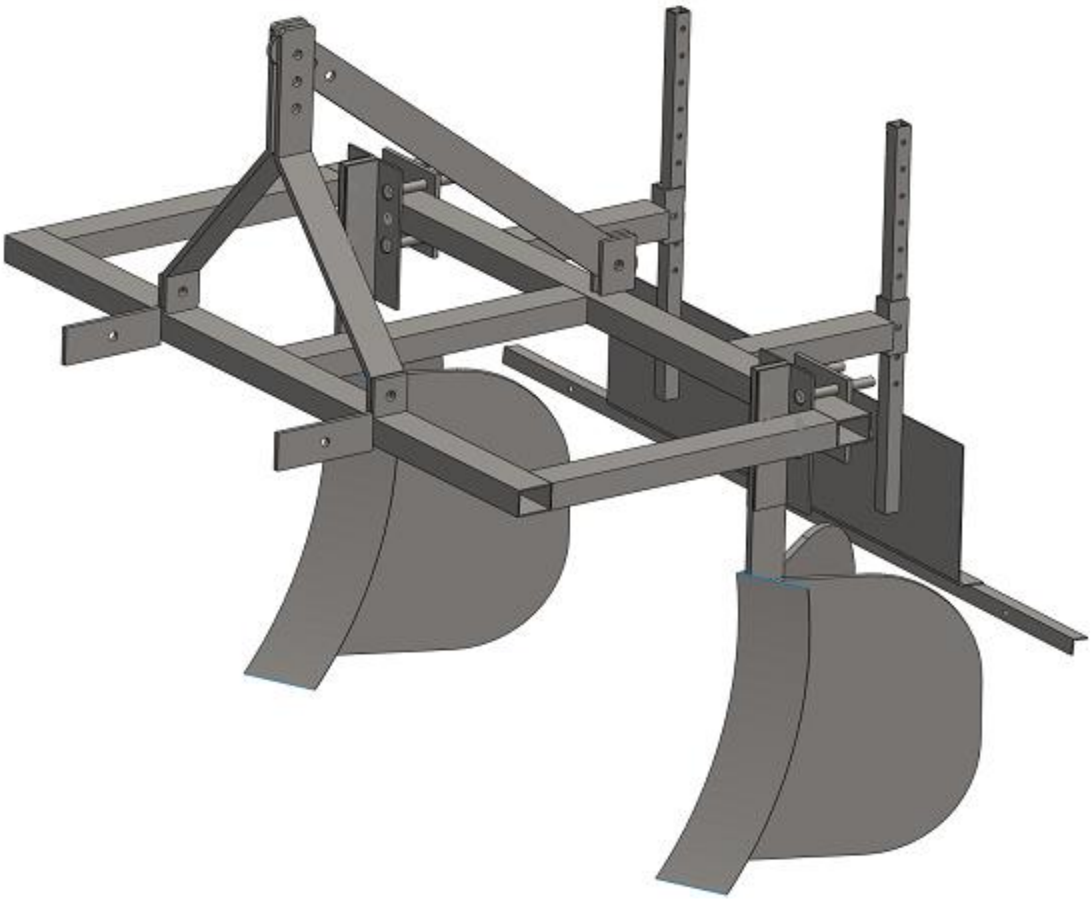


Figure 27. Side view of the developed broad bed maker

Figure 28. Detailed view of the developed broad bed maker

Table 7. Specifications considered for the development of broad-bed maker

No.	Particulars	Specifications & Descriptions
1	Name of implement	Broad-bed maker (BBM)
2	Power source	Tractor (100 hp)
3		Overall dimensions
	Length, mm	1280
	Width, mm	1500
	Height, mm	1483
4		Hitch
	System	Three-point hitch (Category – II for 100 hp tractor); Extended out from main frame
	Material of fabrication	Hitch – MS flat bar (70 mm x 12 mm) Hitch base – MS rectangular hollow section (70 x 50 mm x 5 mm)
	Dimension	ASAE S217.12 (ISO 730)
5		Frame
	Material of fabrication	Mild steel rectangular hollow section (70 x 50 mm x 5 mm)
	Dimension (length x width)	1500 mm x 600 mm
6		Tines and furrow opener

	Type	Shoe type
	Furrow opener	Wing – MS sheet metal (500 mm x 500 mm x 4 mm)
	Tines	MS flat (70 mm x 30 mm); length 700 mm rectangular cross section
	No of furrow opener	2
7	Bed former	Mild steel sheet, 1500 mm x 600 mm x 3 mm Angle iron, 30 mm x 30 mm x 3 mm, SHS, 30 mm x 30 mm x 3 mm

3.9. Field Evaluation of Developed Broad-bed Maker

The prototype tractor-operated bed former was tested and evaluated at actual field conditions. It is subjected to evaluate in the field condition at research farm of DZRC location dominated by vertisols. A 100 hp tractor (specifications in Appendix III) was selected to operate the prototype bed-maker. Three plots of each size 50 m x 6 m = 300 m^2 were utilized for broad-bed making. The performance parameters of broad-bed maker such as speed, depth, field capacity, field efficiency, draft requirement, slippage, and fuel consumption were observed.

Figure 29. Field test of developed BBM

The following parameters was used for evaluating the prototype for a field of 0.09 ha area for field test of the prototype.

3.9.1. Materials

Stopwatch: A stopwatch, measuring a minimum of one-tenth of a second and a maximum of 12 hours was used to record the travel speed and time required to cover the measured area during the test.

Metallic and steel tape: A 50 m metallic tape and 3 m steel tape was used for measuring and marking the layout of the test plot. A steel tape was also use for measuring the depth and top width of the broad-bed.

Measuring cylinder: A one-liter capacity measuring cylinder with 100 ml graduations was used to measure the fuel consumption of the tractor at the time of field operation.

Dynamometer: A hydraulic pull-type dynamometer of 100 KN capacity was used to measure the draft required to operate the implement in the field.

Weight balance: An electronic weight balance of 5 kg capacity was used to measure the weight of wet and dry soil for the determination of moisture content and bulk density of the soil.

Electric oven: An electric oven was used for drying the soil samples, for the determination of moisture content and bulk density of the soil.

Sample boxes: The sample boxes were used for keeping the soil samples in the oven.

Cone penetrometer: Used to measure soil penetration resistance of the soil from the experimental plot.

Shear meter: Used to measure the shear strength properties of soil.

pH meter: Used to measure the hydrogen ion concentration in soil to determine the alkalinity or acidity.

Conductivity meter: Used to measure the concentration of soluble salts.

3.9.2. Operating parameter

3.9.2.1. Speed of operation

Two poles, 50 m apart, were set in the center of the test run to calculate traveling speed. On the other side, two poles were set in a similar location, 50 m apart, so that four poles would form the corners of a rectangle, parallel to the plot's long edge. The machine's speed was estimated using the time it took to move 50 m between two poles. The machine's traveling speed was calculated by taking the average of these data. Similarly, the forward speed of operation was calculated by observing the distance traveled with the time taken and calculated by the following formula reported by (Rangapara, 2014).

$$S = \frac{L}{t} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (3.17)$$

Where: S = forward speed of the machine, m/s

L = distance traveled, m

t = time taken, s

3.9.2.2. Width of coverage

The width of coverage was determined by measuring the horizontal distance covered by the machine during bed making operation with the help of measuring tape as shown in figure 30.

Figure 30. Measurement of the actual width of bed

3.9.2.3. Measurement of tractor wheel slip

The tractor drive wheel normally slips in all field operations. The tractor wheel slip depends upon the depth of operation and moisture content of the soil. The determination of percent tractor wheel slip was useful to know the approximate loss of power from the ground during actual field operation. The slip will affect the speed of operation and thereby the effective field capacity of the implement. The movement of the tractor wheel in the direction of travel for a given distance under load and at no-load conditions was determined as follows, by (Rangapara, 2014; Prem et al., 2017)

$$\text{Slip}(\%) = \frac{\text{WL} - \text{NL}}{\text{WL}} \times 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.18)$$

Where: WL = number of rotations of the rear wheel with the load.

NL = number of rotations of rear-wheel at no load.

3.9.3. Performance parameters

3.9.3.1. Draft of the implement

Draft measurement was done with the help of a digital dynamometer. The drive tractor along with dynamometer was positioned in front of the test tractor the dynamometer was connected to the front axle of the test tractor with wire rope and clamps and the dynamometer was kept horizontal during the field trial and the implement was attached to the test tractor. The draft of implement was recorded in the field. For no-load reading, the implement was lifted and the draft was recorded. similarly, draft reading is recorded while the machine is in operation. The test tractor was held in neutral during the dynamometer measurement. After each run, the readings were recorded. The results of the draft requirement of implement were calculated by the following formula (Rangapara, 2014; Prem et al., 2017).

$$\text{Draft of implement} = \text{with load draft} - \text{without load draft} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (3.19)$$

Figure 31. Measurement of the draft of broad-bed maker using dynamometer

3.9.3.2. Fuel consumption

To measure the fuel consumption tractor was placed on leveled ground then the fuel tank of the tractor was filled up to the top of the tank before operation. After the completion of the operation, the tractor was placed at a leveled ground and then the tank was again filled with fuel to maintain the original level of fuel quantity of fuel filled in the tank was measured by measuring cylinder.

The quantity of fuel required to make up the original level as before the operation was the actual fuel consumption.

Figure 32. Measurement of fuel consumption

3.9.4. Field capacity and efficiency

The amounts of time the machine is worked at its full rated speed and width in the field under actual working conditions is known as field efficiency (FE) (Nasri et al., 2016). The ratio between the bed-maker productivity under real working conditions and the theoretical maximum achievable productivity is defined as FE (Grisso et al., 2004). The field efficiency is calculated using the effective field capacity (EFC) and theoretical field capacity (TFC). EFC refers to a bedmaker's ability to build a bed in actual field conditions, whereas TFC is a theoretical field capacity calculated by multiplying the width of the machine by the average forward speed (FS) during field operation (Zhou, 2012). Equation 3.20-3.22 is used to compute the FE, TFC, and EFC (ASABE, 2005).

$$\mathrm{FE} = \frac{\mathrm{EFC}}{\mathrm{TFC}} \quad \text{(3.20)}$$

Where, FE is field efficiency (%), EFC is an effective field capacity (ha/h) and TFC is a theoretical field capacity (ha/h).

$$\mathrm{TFC} = \frac{\mathrm{W\ x\ S}}{10} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.21)$$

Where: W = is width of machine (m) and S = is speed of machine (km/h).

$$\mathrm{EFC} = \frac{\mathrm{A}}{\mathrm{T}} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.22)$$

Where: A = is the worked area (ha) and T = is working time (h) which represents time spent in performing the operation from the beginning to the end which includes bed-making, and others like machine setting, adjustment and refueling.

3.10. Economic Evaluation

The cost of bed making was estimated using a cost analysis. To calculate the cost of operations, both fixed and variable expenses were considered. The cost of operation of the tractor-operated prototype broad-bed maker was calculated based on field assessment measurements. To calculate depreciation costs, the straight-line method was used. The following variables were taken into account while calculating the cost of operation. Accurate cost estimates play an important role in every machinery management decision namely when to trade, which size to buy, how much to buy, (Kay et al., 2020).

All calculations were based on ASABE Standards D497.7, 2011(R2020) and Kay et al., 2020.

3.10.1. Fixed cost

Depreciation, interest charges, taxes, insurance, and shelter are all fixed expenditures for a machine. Depreciation accounts for the majority of a machine's overall expenditures. It measures the amount, by which the value of a machine decreases with time, whether it is used or not. There are several methods of calculating depreciation. The most common methods are straight line, declining balance and sum of year digit among. From all of these methods straight line method was generally used (ASABE, 2011).

A. Depreciation

It entails a decrease in the value of a machine due to wear and tear. It is sometimes the most expensive of all charges. Machines degrade, or lose value, for a variety of causes, including machine age, wear and tear, and obsolescence.

Straight line method: - The straight-line depreciation approach reduces the value of the machine by an equal amount each year it is kept. This approach may always be used to predict expenses over a certain time period as long as the salvage value is appropriate for the machine's age. The annual depreciation value can be calculated from the following expression.

$$D = \frac{(P - S)}{(L \text{ x } H)} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. (3.23)$$

Where: D = Average annual depreciation, Birr/h

P = Purchase price, Birr

S = Salvage value, Birr

L = Life of machine, years

H = Annual use of the machine, h

B. Interest on investment

The second major item of expense in agricultural machinery management is interest. The interest is computed using the machine's average value.

$$I = \frac{(P + S)}{2} \text{ x } \frac{i}{100} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.24)$$

Where: I = Interest on investment, Birr

P = Purchase price, Birr

S = Salvage value, Birr

i = Rate of interest

C. Taxes, housing, and insurance = 2 % of the initial investment (purchase price of tractor)

3.10.2. Variable cost

The variable costs of a machine, as the name implies, fluctuate depending on how it is used and are stated as expenses per hour of operation. Maintenance and repair costs are separated from fuel and oil prices. Fuel usage is calculated based on fuel requirements per hectare or hour (Jain and Philip, 2012). Fixed and variable costs are used to compute a machine's overall operating expenses. Labor charges must be applied based on the operation's labor requirements. Variable expenses include repair and maintenance costs, labor costs, fuel costs, and lubricant prices.

Assumptions:

A. Fixed cost

i. Average annual use = 200 h

ii. Life of machine = 15 years
iii. Salvage value = 10 % of the initial cost
iv. Rate of interest at 12 % of capital cost
v. Housing, taxes and insurance cost = 2 % of the initial investment per year

B. Variable cost

i. Fuel cost, = 31 Birr/l
ii. Lubrication cost at 30 % of fuel cost
iii. Labour cost per day = 40 Birr
iv. Repair and maintenance cost = 10 % of initial investment per year.

The sum of fixed and variable costs was used to calculate the overall cost of operation. The overall cost of operation was determined per hour of machine operation. The entire cost of operation for a broad-bed maker was calculated in birr per hour and birr per hectare.

3.11. Experimental Design

The experimental design lies on randomized complete block design (RCBD) in a split-plot arrangement which shows the interaction between two factors. The treatment consists of all possible combinations of all the selected levels. The treatments were speed and depth of operation and common furrow opener (FO) throughout the field trial. Operating speed is the main plot factor, with 3 levels, while depth of furrow is the subplot factor, with 3 levels. There are 3 reps per main plot. The experiment designs could be arranged split-plot, with main plots arranged as an RCBD.

Table 8. Treatment details of experiment in RCBD in split plot design

Main Factor	Operating speed (3)	1.9 km/h 2.3 km/h 2.9 km/h	S1 S2 S3
Sub-factor	Depth of furrow (3)	100 mm 150 mm 200 mm	D1 D2 D3

Statistical Design:	Split plot design
Treatment combination:	3 x 3 x 3 = 27
Plot size:	50 m x 18 m = 900 m^2
Net area:	0.09 ha

Experimental field layout in split plot design

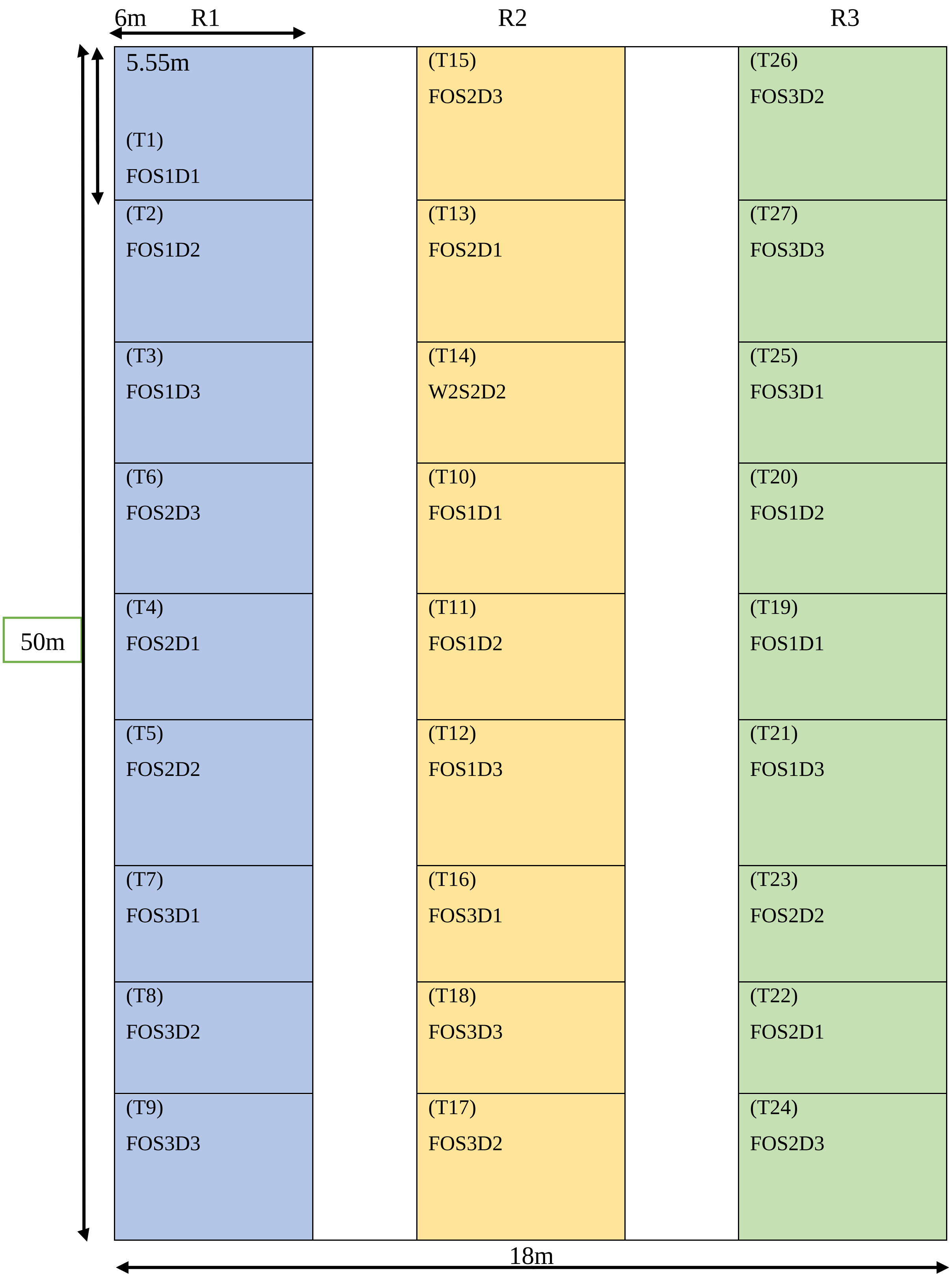


Table 9. Treatment combinations for the experiment

Treatments	Symbols	Treatment combination
T1	FOS1 D1	FO + 1.9 km/h speed of operation + 100 mm depth of furrow
T2	FOS1 D2	FO + 1.9 km/h speed of operation + 150 mm depth of furrow
T3	FOS1 D3	FO + 1.9 km/h speed of operation + 200 mm depth of furrow
T4	FOS2 D1	FO + 2.3 km/h speed of operation + 100 mm depth of furrow
T5	FOS2 D2	FO + 2.3 km/h speed of operation + 150 mm depth of furrow
T6	FOS2 D3	FO + 2.3 km/h speed of operation + 200 mm depth of furrow
T7	FOS3 D1	FO + 2.9 km/h speed of operation + 100 mm depth of furrow
T8	FOS3 D2	FO + 2.9 km/h speed of operation + 150 mm depth of furrow
T9	FOS3 D3	FO + 2.9 km/h speed of operation + 200 mm depth of furrow
T10	FOS1 D1	FO + 1.9 km/h speed of operation + 100 mm depth of furrow
T11	FOS1 D2	FO + 1.9 km/h speed of operation + 150 mm depth of furrow
T12	FOS1 D3	FO + 1.9 km/h speed of operation + 200 mm depth of furrow
T13	FOS2 D1	FO + 2.3 km/h speed of operation + 100 mm depth of furrow
T14	FOS2 D2	FO + 2.3 km/h speed of operation + 150 mm depth of furrow
T15	FOS2 D3	FO + 2.3 km/h speed of operation + 200 mm depth of furrow
T16	FOS3 D1	FO + 2.9 km/h speed of operation + 100 mm depth of furrow
T17	FOS3 D2	FO + 2.9 km/h speed of operation + 150 mm depth of furrow
T18	FOS3 D3	FO + 2.9 km/h speed of operation + 200 mm depth of furrow
T19	FOS1 D1	FO + 1.9 km/h speed of operation + 100 mm depth of furrow
T20	FOS1 D2	FO + 1.9 km/h speed of operation + 150 mm depth of furrow
T21	FOS1 D3	FO + 1.9 km/h speed of operation + 200 mm depth of furrow
T22	FOS2 D1	FO + 2.3 km/h speed of operation + 100 mm depth of furrow
T23	FOS2 D2	FO + 2.3 km/h speed of operation + 150 mm depth of furrow
T24	FOS2 D3	FO + 2.3 km/h speed of operation + 200 mm depth of furrow
T25	FOS3 D1	FO + 2.9 km/h speed of operation + 100 mm depth of furrow
T26	FOS3 D2	FO + 2.9 km/h speed of operation + 150 mm depth of furrow
T27	FOS3 D3	FO + 2.9 km/h speed of operation + 200 mm depth of furrow

Table 10. Technical details of furrow openers used in the experiment

Parameters	Furrow opener/ Ridger
Overall dimensions, L x W x H (mm)	300 x 600 x 750
Power source	Tractor, 100hp
Rake angle, (o)	30
Width of tip of share, (mm)	100
Curved shape and wing angle of: (o)	40
Weight, kg	17.76

3.12. Statistical Analysis

All the data collected during the field performance evaluations was analyzed using Statistix 8 software, a commercial software package developed by the United States Department of Agriculture (USDA). The data was subjected to analysis of variances following a procedure appropriate for the design of the experiment (Gomez and Gomez, 1984).

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

This chapter deals with the outcomes of the study undergone throughout the project period. It includes details of the fabrication and testing of tractor operated broad-bed maker (BBM) under actual field condition. Also, deals with the study related to the physical characteristics of soil, and on-station testing was done to find out the consequences of the interactive effect of forward speed and depth of operation on average bed width, bed height, and draft. Further, the field evaluation of the developed broad-bed maker was done based on results obtained from the on-station evaluation. Finally, the cost developed BBM was calculated. The study's findings were presented and discussed in the following sections.

4.1. Field Evaluation of Developed Broad-bed Maker

The field evaluation was done as per the procedures defined in previous chapter. Results for individual experiments were tabulated in Appendix-1.

Table 11 lists the preliminary observations of the experimental field made prior to field testing.

Table 11. Preliminary observations during operation

Sr. No.	**Particular**	**Observation**
1	Date of operation	April, 2022
	Field condition	
2	Topography	Flat
3	Soil moisture content, % (d.b)	6.63
4	Bulk density, g/cm^3	1.73
5	Type of soil (soil texture)	Vertisol (clay)
6	pH	7.04,7.15
7	EC, ds/m	0.171,0.224
8	Soil penetration resistance, kpa	4547
9	Shear strength, kgf/cm^2	0.959
10	Size of each plot, m^2	50 x 6
11	Land	Roughly leveled (harrowed field)

4.2. Physical Properties of Soil

Figure 33. Measuring the physical properties of the soil

4.2.1. Moisture content of soil

In Appendix-I, the soil moisture content of the experimental field at the time of bed formation was calculated and found to be 6.63 % on a dry basis.

4.2.2. Bulk density of soil

The bulk density of the soil in the experimental plot was determined as 1.73 g/cm^3, as shown in Appendix-I.

4.2.3. Soil penetration resistance

Soil penetration resistance was determined randomly using direct soil penetrometer apparatus at 20 cm depth in three locations of the study area. The average soil penetration resistance of the soil from the experimental plot was found out as 4547 kpa which is in red zone and have severe compaction rating according to ASABE soil compaction standard (ASAE/ASABE S313.3, 1999/ R2018).

Figure 34. Soil penetration resistance test using cone penetrometer

4.2.4. Shear strength

Shear strength of the soil was determined arbitrarily using vane shear meter at three places of the study area. Average shear stress of the soil from the experimental plot was found out as 0.959 kg/cm^2.

4.2.5. pH value of the soil

PH value of the soil samples collected from the experimental plot is given in table 12. The sample was collected from two depths which is 10 and 20 cm from the test plot. The experiments were conducted during April 2022. Soil acidity of the study area for both depths showed an acidic range with pH values of 7.04 and 7.15 in the test plots.

4.2.6. EC value of the soil

Electrical conductivity (EC) value of the soil samples collected from the experimental plots is explained in table 12. The soil salinity of the study area showed EC values of 0.171 ds/m at the depth of 10 cm and 0.22 4 ds/m at the depth of 20 cm. As there was no rain or irrigation given to the plot in this period the salinity remains high in the test plot. leaching of salts can be very high if the rain falls.

4.2.7. Soil texture

Soil textural analysis result is given in Appendix I. The result of hydrometer analysis was plotted in to USDA soil texture triangle to classify the texture as shown in figure 35 and table 12.

In this curve, the percentage of sand, clay, and silt was taken as a reference to draw the result.

Table 12. Laboratory result of the soil

Sl. no	Depth (cm)	pH	EC (ds/m)	Soil texture		
				% Clay	% Silt	% Sand
1	0-10	7.05	0.171	51	35.66	13.34
2	10-20	7.15	0.224	53	29.66	17.34

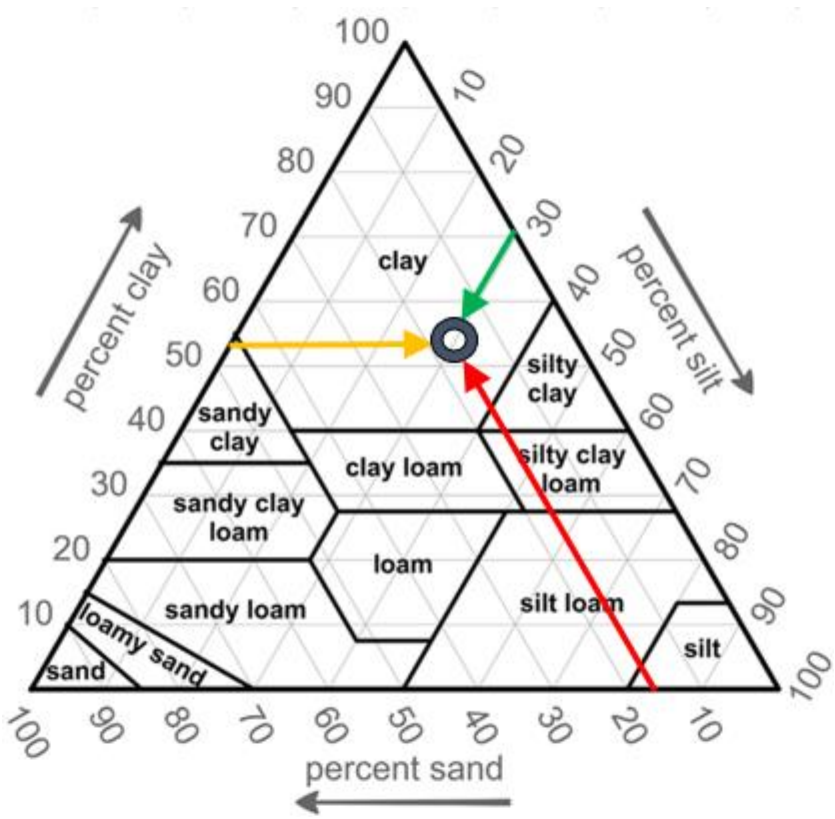


Figure 35. Soil textural triangle indicated clay: 17.34 % sand, 29.66 % silt, and 53 % clay

4.3. Machine Parameter Optimization Under Dynamic Conditions

The tractor-operated broad-bed maker optimization experiments were carried out at the research center's experimental test plot. These studies were carried out to determine the best speed and depth of operation based on the height and top width of the seed beds, as well as the bed maker's draft. The speeds selected were 1.9 km/h, 2.3 km/h and 2.9 km/h speed of tractor and the depths were varied at 10, 15 and 20 cm respectively. The average values of the measured parameters were found out and are given in table 13.

Table 13. Machine parameter optimization under dynamic conditions

Sl.no	Treatment	Speed of operation (km/h)	Depth of operation (cm)	Height of bed (cm)	Top width of bed (cm)	Draft of implement (kgf)
1	S1D1	1.9	10	19.5	126	287.56
2	S1D2	1.9	15	22.5	125.1	318.42
3	S1D3	1.9	20	23.1	124.4	320.20
4	S2D1	2.3	10	20.5	125.2	326.31
5	S2D2	2.3	15	22.9	124.8	338.59
6	S2D3	2.3	20	23.5	124.1	365.04
7	S3D1	2.9	10	22.1	122.5	372.82
8	S3D2	2.9	15	23.4	121.8	375.16
9	S3D3	2.9	20	26	121	388.03
10	S1D1	1.9	10	20.1	125.8	286.46
11	S1D2	1.9	15	22.3	125	328.37
12	S1D3	1.9	20	23.4	124.8	315.80
13	S2D1	2.3	10	20.8	125	324.67
14	S2D2	2.3	15	23	124.3	337.39
15	S2D3	2.3	20	23.3	124	364.87
16	S3D1	2.9	10	22.5	122	360.98
17	S3D2	2.9	15	23.8	121.2	372.93
18	S3D3	2.9	20	25.8	120.9	387.74
19	S1D1	1.9	10	20.3	125.4	265.91
20	S1D2	1.9	15	23.3	125	321.43
21	S1D3	1.9	20	23.9	125	322.47
22	S2D1	2.3	10	23.7	124.8	324.63
23	S2D2	2.3	15	22.8	124.1	349.48
24	S2D3	2.3	20	23.6	124.3	374.36
25	S3D1	2.9	10	22.1	122.2	370.11
26	S3D2	2.9	15	23.9	121	379.52
27	S3D3	2.9	20	26.1	120.5	388.03

4.3.1. Operation depth and speed

Tables 13 and 14 show the results of an analysis of variance (ANOVA) for the top width of the bed in relation to different speeds and depths of operation. The impact of the treatment combination of depth and speed is not significant at the 5% level. The considerable interaction C indicates that the speed of operation affects the formation of the bed's top width. The effect of operation depth is significant. The speed and depth treatment combination were not significant.

At a speed of 1.9 km/h and a depth of operation of 10 cm, the maximum top width of 126 cm was achieved. The top width of the bed was minimal at 15 and 20 cm at the same speed, possibly due to raising the height of the broad-bed. The top width of the bed was found to decrease at speeds of 2.9 and 2.3 km/h and a depth of operation of 20 cm. The top width of the bed formed was also found to decrease as the height of the bed increased in these combinations. As a result, it can be stated that in order to achieve the maximum top width, both the speed and depth of operation must be at their minimum values. The beds with the highest top width and depth formed at 1.9 km/h and 10 cm, respectively. The ultimate goal of using a broad-bed maker is to make the bed as tall as possible.

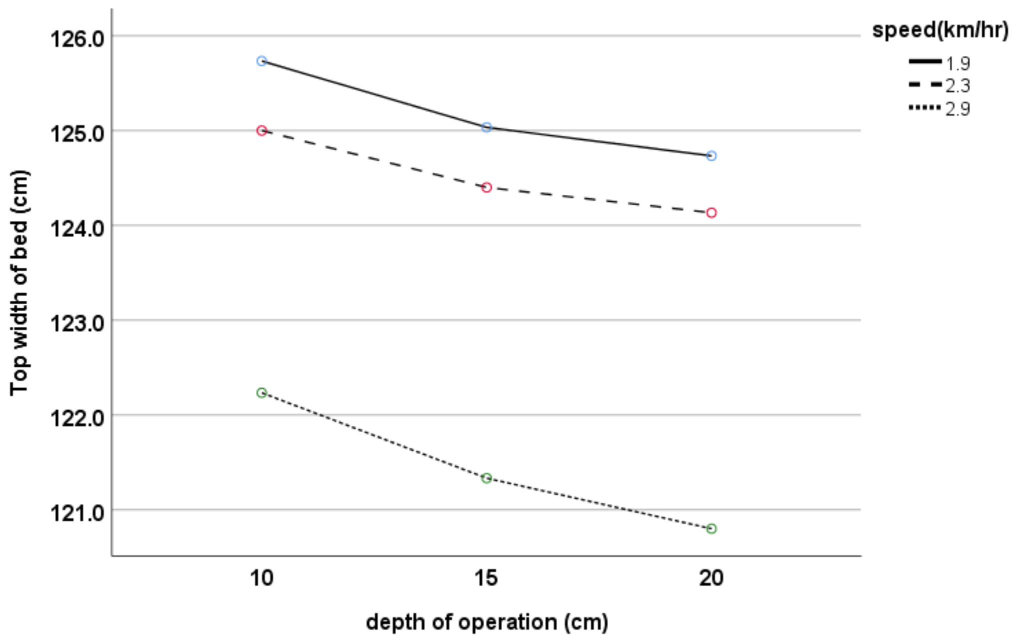


Figure 36. The effect of operational speed and depth on broad-bed top width

Table 14. Effect of speed and depth of operation on top width of bed

Source	DF	SS	MS	F	P
REP(A)	2	0.4022	0.2011		
Depth of operation(B)	2	5.6467	2.8233	30.43	0.0038
Error AXB	4	0.3711	0.0928		
Speed of operation(C)	2	70.6156	35.3078	698.40	0.0000
BXC	4	0.2644	0.0661	1.31	0.3219
Error AXBXC	12	0.6067	0.0506		
Total	26	77.9067			

C.V. 0.18, $P < 0.05$ Significant at 5 % level, $P > 0.05$ Not significant at 5 % level

4.3.2. Broad-bed height

Tables 13 and 15 show the analysis of variance for the height of the bed in relation to different speeds and depths of the operation. The effect of treatment combinations of speed and depth of operation was significant at the 5 % level, showing that depth and speed of operation affect the height of the bed, according to the table. The interaction B x C is not significant. As a result, it's been determined that the maximum height of the broad-bed can be achieved by setting the operating depth to 20 cm and the speed to 2.9 km/h.

At a speed of 2.9 km/h and depths of 15 and 20 cm, the maximum height of broad-bed was achieved. This result could be related to the effect of soil particle buildup caused by a deeper effective depth of operation. As a result, the operating speed has been set at 2.9 km/h. The depth of operation is significant at the 5 % level, according to the analysis of variance (ANOVA).

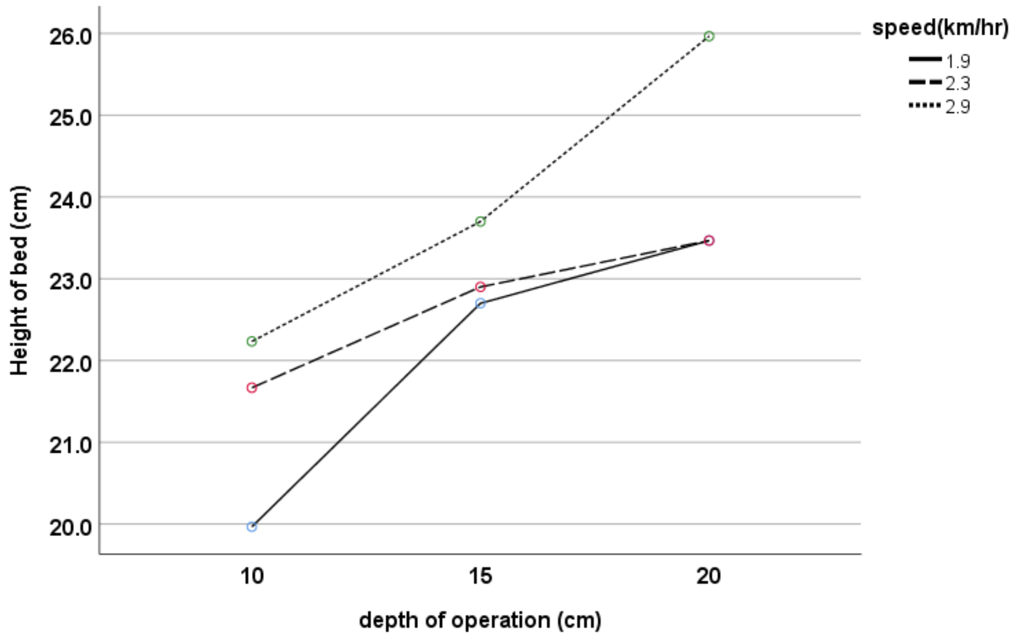


Figure 37. The effect of operational speed and depth on broad-bed height

Table 15. Effect of depth and speed on height of bed

Source	DF	SS	MS	F	P
REP(A)	2	0.6067	0.3033		
Depth of operation(B)	2	33.8422	16.9211	21.21	0.0074
Error AXB	4	3.1911	0.7978		
Speed of operation(C)	2	22.8356	11.4178	19.20	0.0002
BXC	4	6.3956	1.5989	2.69	0.0825
Error AXBXC	12	7.1356	0.5946		
Total	26	74.0067			

C.V. 3.38, P < 0.05 Significant at 5 % level, P > 0.05 Not significant at 5 % level

4.3.3. Draft of the implement

Table 16 shows the analysis of variance for the optimal treatment combination that produces the least draft of the implement in terms of operating speed and depth of operation. The effect of treatment combinations of speed and depth of operations is significant at the 5 % level, according to the table. Figure 38 depicts the influence of speed and depth of operation on the draft of the implement. Furthermore, all interactions between these treatments are significant. The three levels of operating speed and depth are set at 1.9, 2.3, and 2.9 km/h and 10, 15, and 20 cm, respectively.

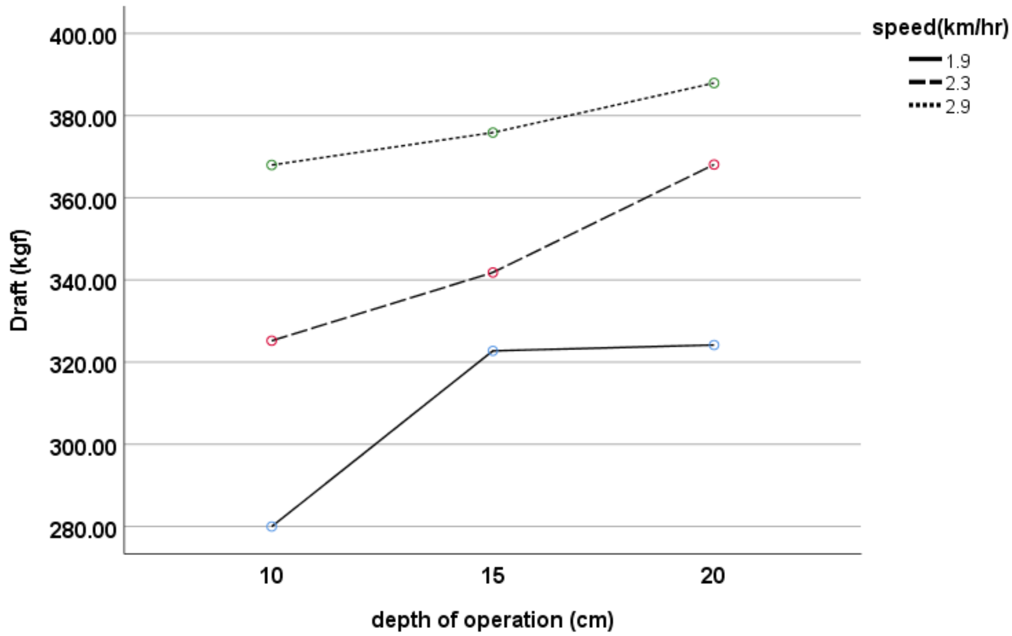


Figure 38. The effect of operational speed and depth on the draft of the implement

Appendix-I shows the effect of different speeds and depths on the draft (kg). As indicated in table 13 and figure 38, draft increased as operating speed and depth increased. At a speed of 2.9 km/h and a depth of operation of 20 cm, the greatest draft observed was 388.03 kgf. At 1.9 km/h and a depth of operation of 10 cm, the minimum draft was 265.91 kgf. As the speed and depth of the operation increased, the volume of soil mass passed through the bed maker increased, and therefore soil resistance grew, resulting in a higher draft value. Because of the increased resistance of movement produced at the tractor, therefore the tractor requires more at higher speeds.

Table 16. Analysis of variance for the draft

Source	DF	SS	MS	F	P
REP(A)	2	17.1	8.5		
Depth of operation(B)	2	5411.9	2705.9	53.80	0.0013
Error AXB	4	201.2	50.3		
Speed of operation(C)	2	22003.1	11001.5	327.37	0.0000
BXC	4	1400.6	350.2	10.42	0.0007
Error AXBXC	12	403.3	33.6		
Total	26	29437.1			

C.V. 1.69, $P < 0.05$ Significant at 5 % level, $P > 0.05$ Not significant at 5 % level

It was also discovered that when the height of the bed increased, the draft increased. The table 13 depicts this phenomenon. When the height of the bed produced reached 26.1 cm, the draft was at its peak. The speed and depth of the operation were also 2.9 km/h and 20 cm, respectively. The highest height of bed attained at 1.9 km/h and all other depths of operation is between 20 and 21 cm. With increased draft, the height of the bed increased from 23 to 26 cm and in all other speeds of operation.

At a speed of 2.3 km/h, the draft was 341.82 kgf, and at a speed of 2.9 km/h, it was 375.87 kgf. As a result, at a speed of 2.3 km/h and a depth of operation of 15 cm, a minimum draft of 341.82 kgf was produced.

To maximize field efficiency, the draft should be kept to a minimum. Results on the influence of speed of operation on the maximum height of seed bed formation showed that it was achievable at a maximum speed of 2.9 km/h. However, at this speed, the draft was maximum 388.03 kgf. Figure 38 depicts these consequences. It is not acceptable since a minimum draft is desirable, particularly with soil working equipment and machinery. As a result, lower operating speeds of 1.9 and 2.3 km/h were considered preferable for significantly decreased draft. The height of the bed formed was quite low at 1.9 km/h, which was not to the desired level for improved leaching impact. As a result, the speed of operation was optimized at 2.3 km/h, and it was concluded that the optimal speed of operation is 2.3 km/h, with a depth of operation of 15 cm, under these conditions.

At medium speeds and depths of operation, the decreased draft was observed. This analysis was then subjected to the LSD All-Pairwise Comparisons Test of draft for depth and speed to determine the best operation combination. The test method evaluated at sixteen subgroups of treatment (homogeneous groups), including seven for bed top width, five for implement draft, and four for bed height. Treatment combination S3D2 and S2D2 are in comparation from their average. Among these treatments the speed of operation 2.3 km/h and depth of operation at 15 cm was chosen as the most suitable combination because of speed and depth of operation reduced the draft.

4.3.4. Tractor wheel slippage

The data concerning the effect of different operational speed and depth on the wheel slippage are presented in appendix-I. Wheel slippage of the tractor operated broad-bed maker was determined using equation 3.18. It was found out as 6.35 %. This may be due to the higher loading effect in broad-bed maker.

Table 17. Determination of slippage of wheel

Operation Speed (km/hr) and depth (cm)	Trial number	Wheel revolutions at 50 m distance covered		
		With load, rev.	Without load, rev.	Slip (%)
S1D1	1	9.25	9	9.52
S2D1	2	9.25	8.75	2.44
S3D1	3	9.5	8.5	10.52
S1D2	4	9.5	9.25	2.63
S2D2	5	9.75	9.25	5.12
S3D2	6	10	9.5	5
S1D3	7	9.5	9	5
S2D3	8	10	9.25	7.5
S3D3	9	10.5	9.5	9.5
Mean		9.6944	9.1111	**6.3589**
SD		0.4104	0.3333	3.0201
CV		4.2330	3.6585	47.494

4.3.5. Tractor fuel consumption

The data stated the effect of operating speed and depth of tractor on the fuel consumption were determined for the area of 300 m^2 and are presented in table 18. From field data collected the average fuel consumption was measured as 3.44 l/ha.

Table 18. Fuel consumption

Plot	Fuel Consumption	
	Fuel consumption to cover 300m^2 (Liter)	Fuel consumption (L/ha)
1	0.15	5
2	0.09	3
3	0.07	2.33
Mean	0.1033	3.44
SD	0.0416	1.3891
CV	40.290	40.342

Fuel consumed by broad-bed maker per unit area (l/ha) decreased as speed operation increased and depth of the operation decreased.

4.3.6. The developed broad-bed height and top width

The broad-bed maker created an average height and top width of 23.6 cm and 124.3 cm, respectively. The findings showed that the height and top width obtained with the developed broad-bed maker are compatible with the suggested crop's agronomic requirements.

4.3.7. Time and labor requirement

The data concerning the effect of different speed and depth on the time to cover 1ha area are presented in table 19. Time consumed by the broad-bed maker per unit area (ha) decreased as speed of the operation increased and depth of operation decreased.

Table 19. Time and labour requirement

Plot	Time and labour requirement		
	Time to cover 300 m^2 (second)	Time to cover 1ha (h)	Number of Labour
1	429	3.97	2
2	473	4.37	2
3	403	3.73	2
Mean	435	4.02	

The broad-bed maker was required two persons for manipulation and operation of bed making activity on the prepared land. The first person was required for to perform farming operation i.e., one skilled labour for operating the tractor and the second one required for adjusting the size of bed former as per the agronomic requirement of the crop if needed.

4.3.8. Determination of field efficiency

The data concerning the effect of different parameter on the theoretical field capacity, effective field capacity and field efficiency to cover 1 ha area are presented in Appendix-I. The data of average effect of different speed on the theoretical field capacity, effective field capacity and field efficiency to cover 1 ha area are presented in table 20.

Size of plot = 50 x 6 = 300 m^2

Width of coverage = 1.5 m

Table 20. Theoretical field capacity, effective field capacity and field efficiency

Plot	Total time required to cover 300 m^2		Total time required to cover 1ha	Theoretical field capacity (ha/hr)	Effective field capacity (ha/h)	Field efficiency (%)
	In (sec.)	In (hr.)	In (hr.)			
1	429	0.119	3.97	0.285	0.252	88.42
2	473	0.13	4.37	0.345	0.231	67
3	403	0.112	3.73	0.435	0.267	62
Mean	435	0.12	4.02	0.355	0.25	**72.5**
SD				0.0755	0.0181	14.035
CV				21.267	7.2333	19.365

Field efficiency of the broad-bed maker was determined using the equation 3.22. The theoretical and actual field capacities of the broad-bed maker were 0.355 ha/hr and 0.25 ha/hr respectively. Hence the field efficiency of the broad-bed maker was 72.5 %.

4.4. Cost Economics and Estimation

The broad-bed maker was required two persons for manipulation and operation of bed making activity on the prepared land. The first person was required to perform farming operation i.e., one skilled labour for operating the tractor and the second one required for adjusting the size of bed former as per the requirement of the farm if needed.

The cost of operation for the developed tractor-operated broad-bed maker was investigated. The cost of depreciation was computed using the straight-line approach. The machine's and tractor's operational costs were determined using assumptions based on the current economic situation. In Appendix-II, along with the computations, the assumptions for cost analysis were examined. The developed BBM was found to cost 379.40 Birr per hour to operate, or 1,254.21 Birr per hectare. The actual operation cost was determined to be 455.66 Birr per hour, or 1,506.31 Birr per hectare, when the custom hiring cost was 20.1 % more than the operation cost (Abiy et al., 2021). In the case of supplying custom hiring, the implement's payback period was found to be 1.54 years if it works for 200 hours per year at a cost of 76.26 Birr per hour. The cost of operation was assessed for the tractor and machine's owner. When hiring both the tractor and the equipment, the cost of the operation may be greater. Furthermore, since variable costs like as fuel and operator costs change, the actual cost of operation changes. Because the developed broad-bed maker had higher bed-making efficiency, as well as lower capital costs for bed-making and better resource utilization, the cost of operation of the produced BBM was justifiable.

The unit cost of a tractor drawn broad-bed maker was determined by calculating the cost of different components and their fabrication cost as given in Appendix-II.

Table 21. Cost summary

No	**Cost variables**	Summary
A	Raw material cost	14,421.28
B	Material wastage 2.5% of A	360.5
C	Production cost (machine + Laboure cost)	3,598.75
D	Overhead cost 5% of C	180
E	Profit 10% of (A+B+C+D)	1,856.05
F	Sells tax 15% of (A+B+C+D+E)	3,062.5
Selling price		**23,479.08**

The result showed that the developed tractor drawn broad-bed maker worked satisfactory and therefore proposed its use for the bed making using 100 hp tractor.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

A prototype of tractor drawn broad-bed maker was developed for bed making operation and its performance was evaluated. The machine was powered by 100 hp New Holland tractor (Appendix III). The bed maker consists of frame, adjustable ridger, shanks, three-point hitch links, connections, bed leveler, bolts, nuts, etc. The field testing of tractor drawn broad-bed maker was carried out at the field of DZARC (Debre-Zeit Agricultural Research Centre). The field was prepared with 25 cm deep, firm, fine structure, smooth and level, relatively free of surface trash. In field test tractor drawn broad-bed maker was operated at different parameters (speed of operation and depth of operation with common plough wing size).

The following conclusions are made from the study tractor drawn broad-bed maker.

1. The average moisture content found out for the experimental plot was 6.63 %.
2. The penetration resistance of the test field soil was observed as 4547 kpa.
3. Soil type of DZARC was heavy clay ("koticha") and its soil textural triangle indicated clay: 13.34 % sand, 35.66 % silt, and 51 % clay at low depth 17.34 % sand, 29.66 % silt, and 53 % clay at high depth respectively.
4. Bulk density of the soil is obtained as 1.73 g/cm^3.
5. The electrical conductivity at different depth of the experimental plot was 0.171 ds/m and 0.224 ds/m respectively.
6. The pH value of the experimental plot at different depth was 7.04 and 7.15 respectively.
7. The average shear strength of the experimental plot was recorded as 0.956 kg/cm^2.
8. The maximum height of the broad-bed was at S3D2 and S3D3 levels of operation.
9. The height of the bed formed at 1.9 km/h was lower than the height formed at 2.3 and 2.9 km/h.
10. The maximum height of bed formed was at speed of 2.3 km/h. To decrease the draft and, at the same time, to keep the height of bed at maximum, speed of operation was set at 2.3 km/h.
11. At a depth of 20 cm, the bed reached its maximum height. The depth of operation was chosen at 15 cm to reduce the draft while maintaining the maximum height of the bed.

12. The average fuel consumption of the broad-bed maker was observed as 3.44 l/ha.
13. The average theoretical field capacity (ha/hr.), effective field capacity (ha/hr.) and field efficiency (%) were 0.355, 0.25, and 72.9 respectively.
14. The cost of fabrication of broad-bed maker was estimated to be about 23,479.08 Birr.
15. The fixed cost was found to be 20.58 Birr per hour whereas, operational cost as 32.32 Birr per hour assuming annual use of 200 h for the tractor operated broad-bed maker. The cost of broad-bed making by developed prototype BBM with operational cost of tractor is 379.40 Birr per hour i.e., 1,254.21 Birr per hectare.
16. The tractor-operated broad-bed former was developed using the optimal parameters.

5.2. Recommendation

The performance evaluation made revealed that the broad-bed maker can be used on the farms, but the following issue must be addressed to promote the bed maker to the farmers.

- Promotion and dissemination of the technologies has to be done to end users.
- Making a good platform to adopt the bed maker to the farmers to use broad-bed maker effectively and efficiently.

Suggestion for future work

The following suggestions may be exploring to advance the performance of tractor drawn broad-bed maker.

- Number of beds covered be increased to improve field capacity and field efficiency of tractor drawn broad-bed maker.
- Precision leveling and well pulverized soil (depends upon the soil) of the land can reduce the irregularities of the bed formed.
- The bed maker may be tested for different other type of soil and feedback received may be used for further design refinements, if any.
- By adding some feature to the machine (like rotary tiller, planter/seed driller) it is possible to increase the performance of the machine, while it performs all this in one pass.

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APPENDIX

APPENDIX-I

Field test

Moisture content, bulk density, and penetration resistance of soil

a) Determination of moisture content of the soil

$$Moisture\ content\ (\%, d.b) = \frac{(Wt.wet\ soil + box) - (Wt.dry\ soil + box)}{(Wt.dry\ soil + box) - (Wt.of\ empty\ box)}$$

Table 22. Appendix I.1. Moisture content and bulk density of soil

Sr.No.	Wt. of wet sample + box (gm)	Wt. of dry sample + box (gm)	Wt. of empty box (gm)	Moisture Content	Moisture Content (%)	Avg. moisture Content (%)
1	179.6	172.4	33.8	0.052	5.19	**6.63**
2	187.1	177.7	34.2	0.066	6.55	
3	190.1	174.6	34.8	0.111	11.09	
4	192.3	181.5	33.9	0.073	7.32	
5	172.2	163.3	34.1	0.069	6.89	
6	209.5	198.6	33.1	0.066	6.59	
7	214.3	200.7	32.7	0.081	8.10	
8	199.4	188.1	33.5	0.073	7.31	
9	189.6	188.6	34.8	0.007	0.65	

Wt. = weight, Avg. = average

b) Determination of bulk density of the soil

The volume of metallic core, $V = \pi r^2 h = 3.14 \times (2.5cm)^2 \times 5cm = 98.125cm^3$

Sr.No.	Wt. of wet sample + box (gm)	Wt. of dry sample + box (gm)	Wt. of empty box (gm)	Dry wt. – empty box wt. (g/cm^3)	Avg. Bulk density (%)
1	179.6	172.4	33.8	138.6	**1.73**
2	187.1	177.7	34.2	143.5	
3	190.1	174.6	34.8	139.8	

4	192.3	181.5	33.9	147.6	
5	172.2	163.3	34.1	129.2	
6	209.5	198.6	33.1	165.5	
7	214.3	200.7	32.7	168.0	
8	199.4	188.1	33.5	154.6	
9	189.6	188.6	34.8	153.8	

c) Penetration resistance of soil

Soil penetration resistance was determined randomly using direct soil penetrometer apparatus at 20cm depth in three locations of the study area. The average soil resistance of the soil from the experimental plot was listed in table below.

Table 23. Appendix I.2. Soil penetration resistance of tested plot

Plot		Penetration resistance, kpa
1	sample 1	4196
	sample 2	5036
	sample 3	4967
2	sample 1	4361
	sample 2	3272
	sample 3	5071
3	sample 1	4864
	sample 2	4657
	sample 3	4499
Average (Avg.)		**4547**

d) Soil strength

Sr no.	Shear strength (τ)	
	kpa	kg/cm^2
1	94.34	0.962
2	93.65	0.955
3	94.14	0.960
Mean	94.04	0.959

e) Hydrometer soil analysis for soil texture determination

Soil from 2mm sieve size and the wight of each 3 sample was 50 g.

Time = 4:20hr at 1st reading and Time = 6:20hr at 2nd reading

Hydrometer calibration temperature = 20 ℃

Suspension temperature at 40 sec = 22 ℃

Suspension temperature at 2 hours = 23 ℃

1st reading => B = 2 and 2nd reading => B = 1

Correction factor = ±0.5 (below 20 ℃ it was an increasing – 0.5 and above 20 ℃ it was an increasing + 0.5)

Hydrometer correction

100 – [(Reading – B) ± correction factor] x 100/50

Reading – B) ± correction factor = corrected hydrometer

Sand determination (%)

100 – [((corrected hydrometer at 40sec) x 100/ dry weight of soil sample)] = % sand in sample

100 – [((43.34 – 2) +1) x 100/50] = 13.34% and 100 – [((42.33 – 2) + 1) x 100/50] = 17.34 %

Clay determination (%)

100 – [((corrected hydrometer at 2hr 40 sec) x 100/ dry weight of soil sample)] = % clay in sample

100 – [((24 – 1) + 1.5) x 100/50] = 51% and 100 – [((23 – 1) + 1.5) x 100/50] = 53 %

Silt determination (%)

100 – (%sand + %clay) = %silt in sample

100 – (13.34 + 51) = 35.66 % and 100 – (17.34 + 53) = 29.66 %

Texture

%sand + %silt + %clay = 100

13.34% + 51% + 35.66 = 100 % and 17.34 % + 53 % + 29.66 % = 100 %

Hydrometer analysis for soil texture determination and EC (ds/m) and pH of the test plot soil

Sr no.	1st reading	Correction factor	Blank (B)	2nd reading	Correction factor	Blank (B)	pH	EC (ds/m)	Soil texture		
1	45	1	2	24.5	1.5	1	7.02	0.169	% clay	% silt	% sand
2	43			23.5			7.06	0.173			
3	45			24			7.04	0.172			
Avg.	44.33			24.0			7.04	0.171	51	35.66	13.34
4	43	1	2	24	1.5	1	7.12	0.223			
5	41			22.5			7.2	0.226			
6	43			22.5			7.13	0.224			
Avg.	42.33			23.0			7.15	0.224	53	29.66	17.34

USDA soil textural triangle; indicated, **clay**: 13.34 % sand, 35.66 % silt, and 51 % clay

Table 24. Appendix I.3. Draft required with and without load condition for (bbm)

Operation Speed (km/hr) and depth (cm)	Sl. no		Draft requirement, kgf			Height of bed (cm)	Top width of bed (cm)
			With load	Without load	Net draft		
SD	S1D1	1	499.65	224.33	275.32	19.5	126
		2	520.04	234.53	285.51	19.6	125.8
		3	550.63	265.12	285.51	19.5	126.2
		4	591.42	275.31	316.11	19.53	126
		5	611.82	336.50	275.32		
		Avg.	554.71	267.15	287.56		
	S1D2	1	560.83	265.12	295.71	22.5	125
		2	601.62	254.92	346.70	22	125
		3	632.21	295.71	336.50	23	125.3
		4	662.80	305.91	356.89	20.5	125.1
		5	683.19	326.30	356.89		
		Avg.	628.13	309.59	318.42		
	S1D3	1	581.22	254.92	326.30	23.1	124
		2	601.62	295.71	305.91	23.3	125
		3	652.60	346.69	305.91	22.9	124.2
		4	693.39	356.89	336.50	23.1	124.4
		5	713.79	387.48	326.31		
		Avg.	648.52	328.33	320.20		
SD	S2D1	1	703.59	397.68	305.91	21	125
		2	785.16	458.86	326.30	20.5	125.1
		3	866.74	489.45	377.29	20	125.5
		4	897.33	540.44	356.89	20.5	125.2
		5	917.73	652.60	265.13		
		Avg.	834.11	507.80	326.31		
	S2D2	1	805.56	458.86	346.70	22.5	124.5
		2	846.35	499.65	346.70	23.5	124.8
		3	856.74	550.63	306.11	22.9	125.1
		4	907.53	560.83	346.70	22.97	124.8
		5	938.12	591.42	346.70		
		Avg.	870.56	532.27	338.59		
	S2D3	1	713.79	418.07	295.72	22.9	124.2
		2	825.95	438.47	387.48	24.1	124
		3	938.12	550.63	387.49	23.5	124.1
		4	968.71	571.03	397.68	23.5	124.1
		5	978.91	622.07	356.84		
		Avg.	885.09	520.05	365.04		
SD	S3D1	1	946.32	571.03	375.29	21.9	122
		2	978.91	601.62	377.29	22.3	122.8

		3	989.12	611.82	377.30	22.1	122.7
		4	999.30	622.01	377.29	22.10	122.5
		5	1009.50	652.60	356.90		
		Avg.	984.63	611.81	372.82		
	S3D2	1	978.91	591.42	387.49	23	121.5
		2	999.30	601.62	397.68	23.5	121.9
		3	1009.50	632.21	377.29	23.7	122
		4	1009.50	652.60	356.90	23.40	121.80
		5	1019.70	662.80	356.90		
		Avg.	1003.29	628.13	375.16		
	S3D3	1	989.12	600.80	388.32	26	121
		2	1009.50	612.59	396.91	26	121
		3	1019.70	625.57	394.13	26	121
		4	1050.29	664.77	385.52	26.0	121.0
		5	1070.68	695.36	375.32		
		Avg.	1027.85	639.81	388.03		
SD	S1D1	1	493.50	221.20	272.30	20	125.5
		2	518.20	231.50	286.70	20.3	126
		3	552.41	266.15	286.26	20	125.9
		4	587.92	268.20	319.72	20.1	125.8
		5	599.85	332.5	267.35		
		Avg.	550.37	263.91	286.46		
	S1D2	1	557.50	268.5	289.00	22	125
		2	603	275.3	327.70	22.9	125
		3	630.7	289.47	341.23	22	125
		4	650	300	350.00	22.3	125.00
		5	661.50	327.60	333.90		
		Avg.	620.54	292.17	328.37		
	S1D3	1	582.23	250.55	331.68	23.6	124.5
		2	610.50	290.92	319.58	23	125
		3	649.32	340.89	308.43	23.6	124.9
		4	690.41	389.50	300.91	23.4	124.8
		5	711.85	393.48	318.37		
		Avg.	648.86	333.06	315.80		
SD	S2D1	1	699.60	400.50	299.10	20.8	125
		2	783.20	455.45	327.75	21	125
		3	859.33	485.31	374.02	20.6	125
		4	899.52	541.50	358.02	20.8	125
		5	915.25	650.65	264.60		
		Avg.	831.36	506.68	324.67		
	S2D2	1	800.50	460.86	339.64	23	124
		2	840.30	495.65	344.65	22.9	124.5
		3	857.75	552.25	305.50	23.1	124.4
		4	905.12	558.19	346.93	23	124.3
		5	940.56	590.27	350.29		

		Avg.	868.84	531.44	337.39		
	S2D3	1	710.95	415.5	295.45	23	124
		2	826.21	440.53	385.68	23.1	124
		3	935.09	549.63	385.46	23.8	124
		4	965.71	568.07	397.64	23.3	124
		5	980.42	620.27	360.15		
		Avg.	883.67	518.8	364.87		
SD	S3D1	1	940.82	569.32	371.50	22.1	122
		2	951.30	600.82	350.48	22.4	122
		3	967.62	613.19	354.43	23	122
		4	1000.50	621.98	378.52	22.50	122
		5	1000.78	650.80	349.98		
		Avg.	972.20	611.22	360.98		
	S3D2	1	969.25	589.57	379.68	23.5	121
		2	1000.50	606.30	394.20	24	121.2
		3	1007.35	629.80	377.55	23.9	121.4
		4	1006.85	649.75	357.10	23.80	121.2
		5	1021.30	665.15	356.15		
		Avg.	1001.05	628.11	372.93		
	S3D3	1	990.15	601.27	388.88	26	120.7
		2	1005.30	615.60	389.70	25.6	121
		3	1021.55	627.75	393.80	25.8	121
		4	1045.35	665.21	380.14	25.8	120.9
		5	1081.57	695.36	386.21		
		Avg.	1028.78	641.03	387.74		
SD	S1D1	1	500.12	223.55	276.57	20.3	125
		2	517.56	231.31	286.25	20.2	125.5
		3	555.11	269.58	285.53	20.5	125.7
		4	587.30	274.22	313.08	20.3	125.4
		5	607.89	339.74	268.15		
		Avg.	533.59	267.68	265.91		
	S1D2	1	561.80	265.12	296.68	23.3	125
		2	600.65	254.92	345.73	23.5	125
		3	635.35	293.70	341.65	23.1	125
		4	662.80	320.75	342.05	23.3	125
		5	687.33	326.30	361.03		
		Avg.	629.58	308.15	321.43		
	S1D3	1	579	254.92	324.08	23.9	125
		2	605.60	290.71	314.89	23.5	125
		3	650.74	343.89	306.85	24.4	125
		4	693.39	355.11	338.28	23.9	125
		5	715.80	387.48	328.32		
		Avg.	648.80	326.42	322.47		
SD	S2D1	1	700	400.67	299.33	23.5	124.5
		2	785.23	453.42	331.81	23.9	124.8

		3	860.50	488.53	371.97	23.7	125.1
		4	893.37	540.44	352.93	23.7	124.8
		5	919.73	652.60	267.13		
		Avg.	831.76	507.13	324.63		
	S2D2	1	805.23	461.58	343.65	22.5	124
		2	850	499.65	350.35	23.2	124.2
		3	856.74	501.63	355.11	22.8	124.1
		4	909.50	560.83	348.67	22.8	124.1
		5	941.12	591.42	349.70		
		Avg.	872.51	523.02	349.48		
	S2D3	1	710.50	420.05	290.45	23.5	124.5
		2	828.87	429.47	399.40	23.7	124.1
		3	940.15	551.65	388.50	23.6	124.3
		4	970.81	625.08	345.73	23.6	124.3
		5	970.81	523.05	447.76		
		Avg.	884.22	509.86	374.36		
SD	S3D1	1	943.32	569.05	374.27	22	122.1
		2	975.80	602.05	373.75	22.5	122
		3	990.15	615.01	375.14	21.8	122.5
		4	1000.50	625.75	374.75	22.1	122.20
		5	1005.25	652.60	352.65		
		Avg.	983	612.89	370.11		
	S3D2	1	978.91	595.35	383.56	23.5	121
		2	999.30	605.75	393.55	24.3	121
		3	1009.50	635.21	374.29	23.9	121
		4	1009.50	655.80	353.70	23.90	121
		5	1010.28	667.80	342.48		
		Avg.	1001.5	631.98	369.52		
	S3D3	1	989.12	600.80	388.32	25.8	120.3
		2	1009.50	612.59	396.91	26.5	120.7
		3	1019.70	625.57	394.13	26	120.5
		4	1050.29	664.77	385.52	26.10	120.50
		5	1070.68	695.36	375.32		
		Avg.	1027.85	639.81	388.03		

f) Determination of slippage of wheel

Wheel slippage (%) of power transmission wheel was computed by using the formula:

$$\text{Slip}(\%) = \frac{\text{WL} - \text{NL}}{\text{WL}} \times 100$$

Where: WL = number of rotations of the rear wheel with the load.

NL = number of rotations of rear-wheel at no load.

Table 25. Appendix I.4. Determination of slippage of wheel

Operation Speed (km/hr) and depth (cm)	Trial number	Wheel revolutions at 50m distance covered		
		With load, rev.	Without load, rev.	Slip (%)
S1D1	1	9.25	9	9.52
S2D1	2	9.25	8.75	2.44
S3D1	3	9.5	8.5	10.52
S1D2	4	9.5	9.25	2.63
S2D2	5	9.75	9.25	5.12
S3D2	6	10	9.5	5
S1D3	7	9.5	9	5
S2D3	8	10	9.25	7.5
S3D3	9	10.5	9.5	9.5
	Mean	9.6944	9.1111	**6.3589**
	SD	0.4104	0.3333	3.0201
	CV	4.2330	3.6585	47.494

g) Determination of field capacity and field efficiency

The data about the effect of different speed and depth operation on the theoretical field capacity, effective field capacity, and field efficiency to cover 1 ha area.

Size of plot = 50 x 6 = 900 m^2

Width of BBM = 1.5 m

Table 26. Appendix.I.5. Determination of field capacity and field efficiency

Plot	Total time required to cover 300 m2		Total time required to cover 1ha	Theoretical field capacity (ha/hr)	Effective Field Capacity (ha/h)	Field Efficiency (%)
	In (sec.)	In (hr.)	In (hr.)			
1	429	0.119	3.97	0.285	0.252	88.42
2	473	0.13	4.37	0.345	0.231	67
3	403	0.112	3.73	0.435	0.267	62
Avg.	435	0.12	4.02	0.355	0.25	**72.5**
SD				0.0616	0.0181	14.035
CV				17.365	7.2333	19.365

APPENDIX-II

Table 27. Appendix.II.1. Cost of fabrications of broad-bed maker

A.	**Materials**	Length (m)	Quantity (kg)	Cost (Birr/kg)	Cost (Birr/m)	Cost (Birr)
	Hollow Section					
	Rectangular Hollow Section (RHS)					
	70 x 50 x 5 mm	4.56	31.46		983.33	4,483.98
	Square Hollow Section (SHS)					
	30 x 30 x 3 mm	1.5	3.76		340	531
	40 x 40 x 3 mm	0.2	0.69		440	88
	Flat Bar					
	Mild steel flat bar					
	70 x 12 mm	3.36			270	907.2
	70 x 15 mm	1.40			350	490
	Sheet Metal					
	Mild steel sheet metal					
	3.0 mm	0.315 m^2			4,700 m^2	740.25
	4.0 mm	1 m^2			5,150 m^2	2,575
	Welding - Electrode					
	Welding - Electrode					
	Ø 2.5 mm		1 pkt	320/pkt		320
	Ø 3.2 mm		1 pkt	370/pkt		370
	Angle Iron					
	Mild steel angle					
	25 x 25 x 3 mm	1.56	1.73		291.5	454.8
	30 x 30 x 3 mm	1.72	2.34		320.8	551.8
	70 x 70 x 6 mm	1.04	6.64		416.6	433.25
	Nuts and Bolts					
	M10 x 70		2 pcs			160
	M10 x 150		2 pcs			200
	M16 x 100		5 pcs			400
	M16 x 120		1 pcs			120
	M20 x 130		8 pcs			1,120
	Paint					
	Anti-rust		2 lit			165
	Normal paint		2 lit			312
	Total material cost					**14,421.28**
B.	**Labour cost**					**531.25**
	Total cost (A+B), Birr					**14,952.53**

Table 28. Appendix.II.2. Machine and labour cost

Type of machine	Machine Birr/hr	Working hour	Total cost (Birr)	Labour cost/hr	Working hour	Total Price (Birr)
Universal metal cutting	85	11	935	12.5	8	100
Welding machine	35	6	210	12.5	7	87.5
Power hack saw	25	2	50	12.5	2	25
Lath machine	155	0.5	77.5	12.5	0.5	6.25
Radial drill machine	55	5	275	12.5	15	187.5
Grinding machine	45	6	270	12.5	9	112.5
Bending machine	1,250	1	1250	12.5	1	12.5
Sub total			**3,067.5**			**531.25**

Table 29. Appendix.II.3. Cost summary

No	**Cost variables**	Summary
A	Raw material cost	14,421.28
B	Material wastage 2.5% of A	360.5
C	Production cost (machine + labour cost)	3,598.75
D	Overhead cost 5% of C	180
E	Profit 10% of (A+B+C+D)	1,856.05
F	Sells tax 15% of (A+B+C+D+E)	3,062.5
Selling price		**23,479.08**

Cost of bed making with developed prototype broad-bed maker

Cost of operation of tractor

Facts and assumption,

Initial cost of tractor, C	- 160,000 birr
Life of tractor, L	- 15 years
Average annual use of tractor, H	- 216 h per year
Interest rate per year, i	- 12 %
Salvage value, S	- 10 % of C
Taxes, housing & insurance per year, M	- 2 % of C
Repair & maintenance, R	- 10 % of C
Fuel cost, F	- 31 birr/l
Fuel consumption	- 3.44liter per hour
Lubrication cost	- 30 % of F
Operator's charge	- 210 birr /day of 8 h

Table 30. Appendix.II.4. Cost of operation of tractor

Fixed cost	Depreciation	$= \frac{(C - S)}{(L\ X\ H)}$	=44.44 Birr/h
	Interest	$= \frac{(C + S)}{2H} X \frac{i}{100}$	=48.88 Birr/h
	Taxes, housing & insurance	$= \frac{C}{H} X \frac{M}{100}$	=14.81 Birr/h
		Total fixed cost	**=108.13 Birr/h**
Variable cost	Fuel cost	= 3.44 L/h x 31Birr/h	=106.64 Birr/h
	Lubrication	= 0.30 x Fc	=31.99 Birr/h
	Repair & maintenance	$= \frac{C}{H} X \frac{R}{100}$	=74.07 Birr/h
	Wages of tractor driver	= 200 Birr/day of 8h	=26.25 Birr/h
		Total variable cost	**=238.95 Birr/h**
		Total operating cost of tractor, TOCT	**=347.08**

Cost of operation of developed prototype broad-bed maker

Facts and assumptions,

Initial cost of bed maker, C	- 23,479.08 Birr
Life of tractor, L	- 10 years
Average annual use of tractor, H	- 200 h per year
Interest rate per year, i	- 12 %
Salvage value, S	- 10 % of C
Taxes, housing & insurance per year, M	- 2 % of C
Repair & maintenance, R	- 10 % of C

Table 31. Appendix.II.5. Cost of operation of developed prototype broad-bed maker

Fixed cost	Depreciation	$= \frac{(C - S)}{(L\ X\ H)}$	= 10.56 Birr/h
	Interest	$= \frac{(C + S)}{H} X \frac{i}{100}$	= 15.5 Birr/h
	Taxes, housing & insurance	$= \frac{C}{H} X \frac{M}{100}$	= 3.52 Birr/h
		Total fixed cost	**= 20.58 Birr/h**
Variable cost	Repair & maintenance	$= \frac{C}{H} X \frac{R}{100}$	= 11.74 Birr/h
		Total variable cost	= **11.74 Birr/h**
Total operating cost of BBM, TOCBBM			= **32.32 Birr/h**

Cost of bed making with developed prototype broad-bed maker = TOCT + TOCBBM

= **379.40 Birr/h**

Total cost per hectare, Birr

$$Total\ cost\ per\ hectare, Birr = \frac{total\ cost\ per\ hour\ for\ BBM + Tractor}{Field\ capacity}$$

Total cost per hectare, Birr = 1,254.21 Birr/ha

APPENDIX-III

Table 32. Appendix.III.1. Specification of tractor used for preliminary test

Specification	Value
Brand	YTO
Model	YTO-404
Variants	2WD
Engine Detail	YTR3105, diesel, 3-cylinder, liquid-cooled
Overall length, cm	354
Overall width, cm	167
Overall height, cm	155
Ground clearance, cm	4
Min. Turning Radius(M)	≤3.5±0.4
Weight, kg	1920 kg
Engine output, Kw/Hp	29.4 /39.4
Rotation speed, rpm	2200
Fuel	Diesel
Fuel tank capacity, Lit	50
Tires	7.5-16
Front:	
Rear:	11.2-28
Wheelbase, cm	189
Gear shift, forward/backward	8/2
Speed range (km/h),	1.63-33.52/2.9-13.38
Power Take-off (PTO), Rear RPM: live	540/1000
Chassis	4x4 MFWD 4WD
Steering	Full hydraulic
Brakes	Oil immersed, wet disk type
Clutch	9-inch, dry, single action clutch
Three-point linkage category	Three-point linkage category II
Tractor hitch, Rear lift, kg	775
Tilling depth control mode	Position control
Operator	1 person

Source: YTO 404 user manual.

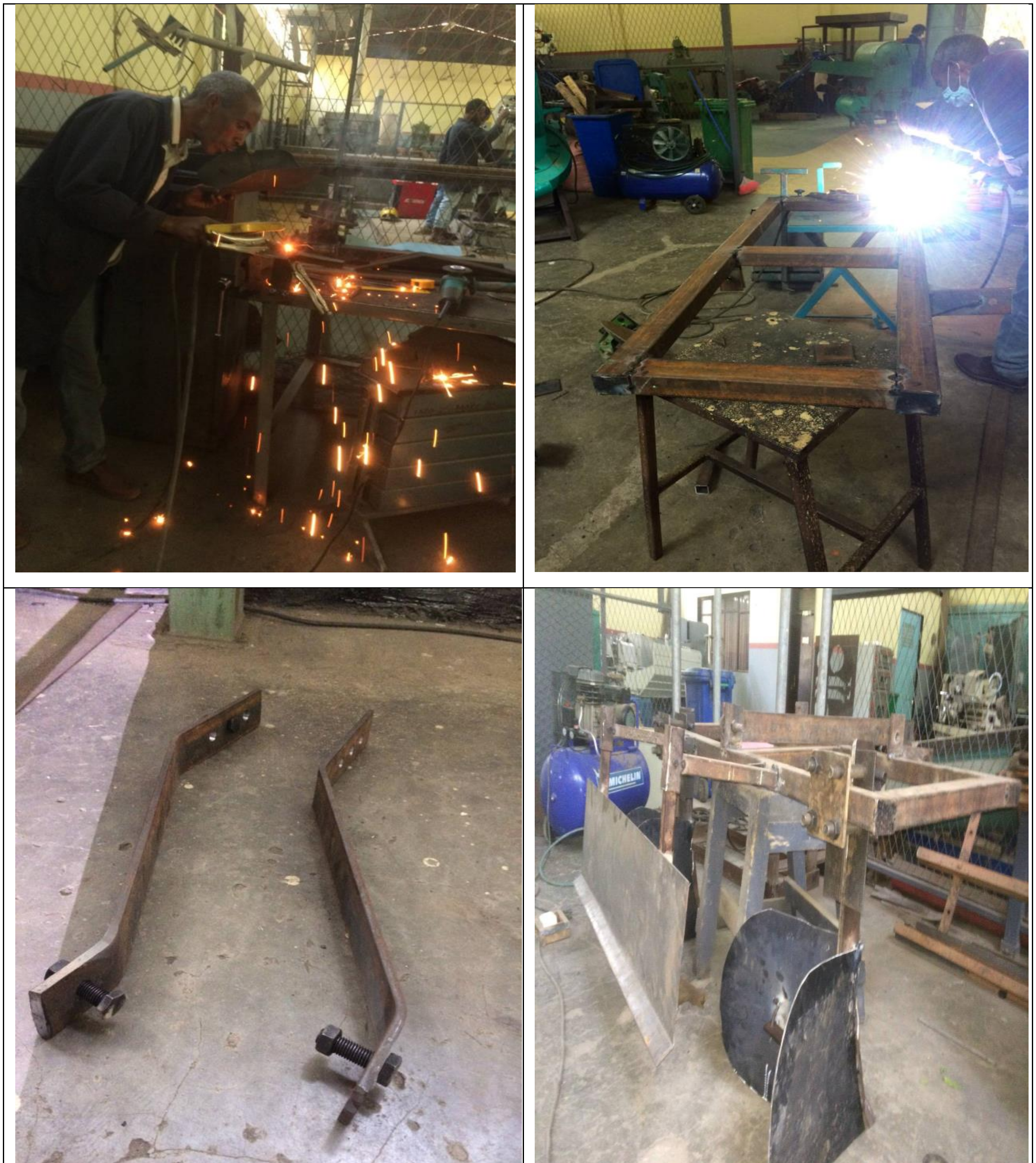
Table 33. Appendix.III.2. Specifications of tractor used for field evaluation of prototype

Manufacturer	New Holland
Model	Fiat 100-90
Engine	
Type	Fiat 8065.06 with intercooler diesel, 6-cylinder, liquid-cooled
Air Cleaner	dry type
Engine Performance	
	Advertised Engine Power, Rated, hp (kW) - 100 (74.6) Maximum Engine Power, hp (kW) - 109 (81) Rated Engine Speed, rpm - 2500 Fuel Tank capacity, gal (L) – 35.1 (132.9)
Fuel type	Diesel
Transmission	
Clutch	Dry disc
Gear Box	15-speed synchronized, 20-speed creeper
Brakes	Hydraulic wet disc
Chassis	4x2 2WD, 4x4 MFWD 4WD (100-90DT)
Hydraulics	
Type	Open center
Transmission oil	45.4 L
Rear lift capacity: (at 24"/610mm)	2035 kg
3 Point hitch (Rear Type)	Category II
Depth & draft control	Automatic
Steering	
Type	Hydrostatic power
Power Take-off (PTO)	
Type	Independent; Live; Continuous
Rear RPM	540/1000 ground
Engine RPM	540@2124, 1000@2409
Wheels & Tyers	
Wheelbase	2580 mm
Length	399 cm
Height	266 cm
Front	11.00-16 (2WD), 12.4/11-28 (4WD)
Rear	16.9/14-38
Electrical System	
Battery	System Rating, Volts - 14
Alternator	Alternator Rating, Amps - 90 std; 200 opt.
Dimensions & Weight of Tractor	
Total weight	4280 kg, 4670 kg(4WD)
Clearance (Front Axle)	51 cm (4WD)
Front axle load	1496 kg
Rear axle	78 by 2555 mm
Front tread	153 to 204 cm (2WD)
Drawbar	
Drawbar Description	Swinging, Adjustable length, Category 2

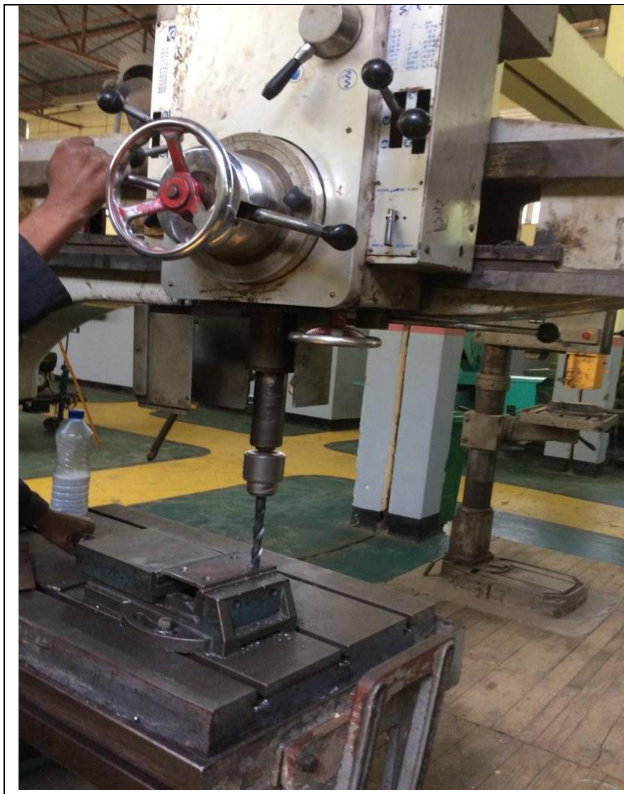
Source: New Holland 100-90 user manual

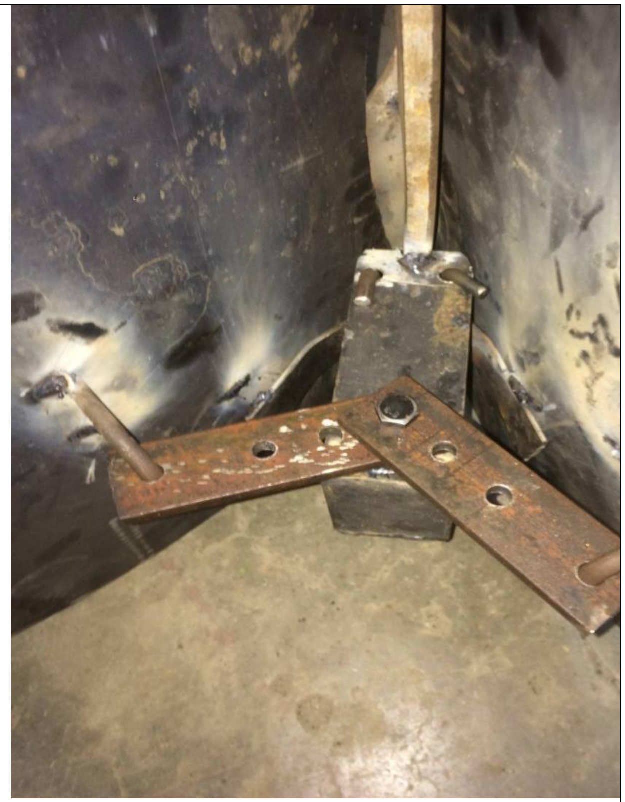
APPENDIX-IV

Pictures showing fabrication and performance evaluation of tractor drawn broad-bed maker








100-90 NEW HOLLAND


100-90 NEW HOLLAND


NEW HOLLAND 100-90