Design, Fabrication and Testing of Animal Drawn Multiple Mouldboard Plough

Abebe Firew Guadie[1] and Yonas Mitiku Degu[2(✉)]

[1] Department of Mechanical Engineering, Technology College, Debre Markos University, Debre Markos, Ethiopia
abe77mulu@gmail.com

[2] Faculty of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Bahir Dar, Ethiopia
yonasm@bdu.edu.et

Abstract. The Ethiopian Ard plough is the most commonly used farm tool in Ethiopia. Nevertheless, using this plough as farm tool is labour intensive, time taking, making shallow depth and narrow cutting width. Thus, this research is initiated to come up with a solution to the aforementioned problems. Therefore, the objectives of this research were to model the basic components of animal drawn multiple mouldboard plough, to fabricate and test the prototype. Eight alternative options were considered for conceptual design among these, without seat to operator, two wheels, two handles and beam attachment design alternative is selected using merit-demerit analysis, pairwise and direct matrix ranking methods. In addition, after the detail design, the prototype is fabricated in Bahir Dar University Institute of Technology Workshop using locally available materials and tested using oxen and horses as draft animals in two most dominant soil types such as Nitrosol and Vertisols at Burie and Gozamin districts of East and West Gojjam Zones of Amhara regional state respectively. The results of the field test reveals that there is a significant difference between Ard plough and the newly designed prototype in time requirements to plough the same plot of land, draft force requirements and cutting width. The newly designed prototype reduces time spent and increasing cutting width during primary tillage. The draft force requirement of both Ard plough and multiple mouldboard plough is higher at Nitrisols than Vertisols. The multiple mouldboard plough cut of width and depth can be adjusted to go along with the available draft animal for optimum field operation performance.

Keywords: Multiple mouldboard plough · Ard plough · Merit-demerit analysis · Pairwise comparison · Conceptual design

1 Introduction

The rural population in most developing countries which represents 80–95% are practicing small scale farming. Though the small-scale farming system is of subsistence type, it plays a very important role in the economy of the countries, since the mass of the agricultural production is from this sector. However, agriculture implements used in these countries are inefficient, time consuming and demand a great deal of physical

F. A. Zimale et al. (Eds.): ICAST 2018, LNICST 274, pp. 206–224, 2019.
https://doi.org/10.1007/978-3-030-15357-1_17

strength while putting them in to use. Using these farm implements cannot increase the agriculture productivity unless improved agricultural technologies are used. The history of animal traction in eastern and southern Africa, with the exception of Ethiopia, started with the introduction of ox-plough by the missionaries. In Ethiopia the animal power has been used for thousands of years [1, 2].

The Ethiopian Ard plough called Maresha is using by most of the farmers for seed bed preparation. Maresha is made by wooden parts based on the farmer's experience from locally available wood variety. Pair of ox and horse is the main source of draft animal power in Ethiopia [2] (Fig. 1.).

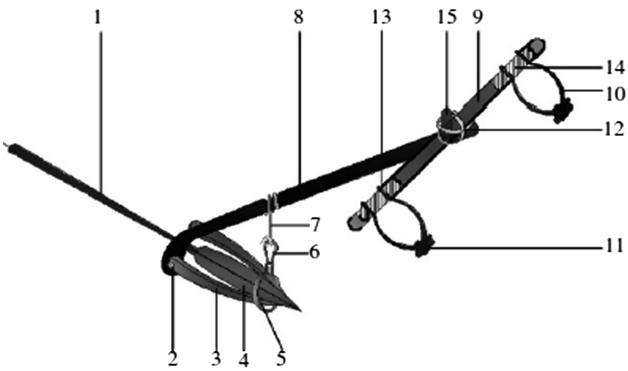

Fig. 1. Parts of Ethiopian Ard plough (Maresha) [5]: (1) handle; (2) wooden pin; (3) side-wing; (4) ploughshare; (5) lower metal loop; (6) upper metal loop; (7) leather stripe or rope (8) beam; (9) yoke; (10) neck holder sticks; (11, 12) leather strap or rope; (13) rubber as washer; (14) leather for safety; (15) centring pin.

Despite, the presence of sufficient livestock population in Ethiopia which can be used as source of draught forces; animal powered technologies are under-utilized due to wrong perception by many decision makers which leads the promotion of animal draught represents being backward. The factors affecting the draught requirements of an animal drawn mouldboard plough are soil type, soil moisture, ploughing speed, depth and width of the furrow slice, mouldboard type, and soil to metal friction characteristics of the soil engaged components [3, 4]. The power requirement of tillage implements is an important design consideration particularly for animal drawn implements, where the power is limited. Several researchers and organizations repeatedly attempted to replace or modify Maresha plough by modern mouldboard plough; farmers rejected the ploughs for its heavy weight, high draft power requirement, difficulty to repair, high cost and, complicated adjustments. Hence they are still using the traditional plough as a farm implement. However, this farm implements are labour intensive, time taking and narrow cutting width. On the contrary, the use of tractors by the peasant farmers is not an economical due to lack of capital, low capability of local industry, lack of skilled personnel, small farm size, and slow industrial development and crop varieties not amendable to tractorization. Thus, it was imperative to modify the present mouldboard plough by increasing the number of mouldboards using light and strong metals to minimize draught power, increase width of slices, enhance speed of operation, and making less labour intensive with minimum cultivation time [5]. Therefore, this study was executed with the objectives of proposing different conceptual design; evaluate, selecting optimum concept, modelling and analysis of the critical components, fabricating and field performance testing of the prototype. For the purpose of validation, comparison of Ard plough and the mouldboard plough prototype.

2 Materials and Methods

2.1 Materials and Tools

A pair of ox and horse is used as draft power in the field experiment because of its vast availability and common usage in the study areas.

A pocket balancer which is modified to measure the draft force was prepared in the workshop, in addition ruler and stop watch also used in the field experiment (Fig. 18).

Moreover, two full set of traditional Ard plough and the newly designed and fabricated animal drawn multiple moldboard plough is used on the field performance test (Figs. 19 and 20).

2.2 Methods

In this study, different possible concepts of animal drawn multiple moldboard plough were proposed with its working principles. The proposed alternatives were evaluated against selection parameters. Based on pairwise ranking, the selection parameters prioritized and relative weights were set. Each proposed concepts was evaluated to choose the optimum design by measure its overall performance. Concepts which scored higher total points (sum of the product of the relative weight and scored value out of eleven) are selected and the detail analysis carried out. The analyses end with by providing the geometric dimension of multiple moldboard plough with all mountings and accessories. Then the prototype was fabricated and assembled and floor test was carried out in the workshop. After that, it is brought in to actual field for in-situ test. Once the shop tests are completed it will go for further testing to the actual field test. The experimental sites are East and West Gojjam Zones, Amhara Regional State, Ethiopia dominantly Nitrisols and Vertisoils soil. Finally the test results were recorded and analyzed.

3 Conceptual Design

Conceptual design is the method of developing different ideas by considering the working mechanism and structure of the product. It is also a description of the proposed system in terms of, a set of integrated ideas and concepts, about which a design must do, behave, and accomplish the stated requirements and to be understandable by the users in a way it is applicable [6].

3.1 Animal Drawn Multiple Mouldboard Plough Alternative Design

Four arrangements of multiple mouldboard plough were conceptually proposed depending on; hitch attachments, number of wheels and number of handle and position of operator. Besides each arrangement has two options for the position of the operator (with seat and without seat); number of wheels (one wheel and two wheels); number of handles (one handle and two handles) and for the plough and yoke attachment there are also two options (beam or chain). In relation to the four arrangements twelve options were obtained. However, having seat for the operator on the top of the implement has no relationship with number of handling and one wheel. Therefore eight alternatives were considered for further conceptual development and selection. The proposed conceptual design alternatives were modelled for further understanding of the abstraction as depicted from Figs. 2, 3, 4, 5, 6, 7, 8 and 9.

1. Seat to operator, two wheels and beam attachment (Fig. 2)
2. Seat to operator, two wheels and chain attachment (Fig. 3)
3. Without seat to operator, one wheel, one handle and beam attachment (Fig. 4)
4. Without seat to operator, two wheels, one handle and chain attachment (Fig. 5)
5. Without seat to operator, two wheels, two handles and chain attachment (Fig. 6)
6. Without seat to operator, two wheels, two handles and beam attachment (Fig. 7)
7. Without seat to operator, two wheels, one handle and chain attachment (Fig. 8)
8. Without seat to operator, one wheel, one handle and beam attachment (Fig. 9).

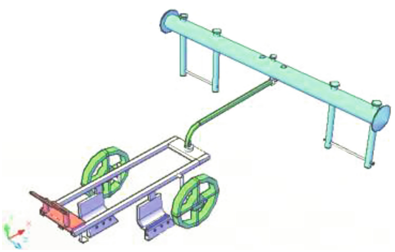

Fig. 2. 1st alternative (conceptual design)

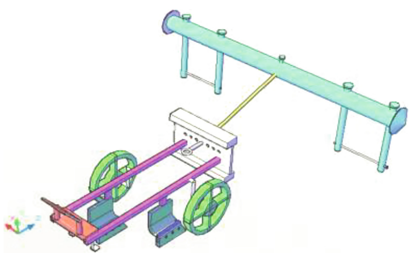

Fig. 3. 2nd alternative (conceptual design)

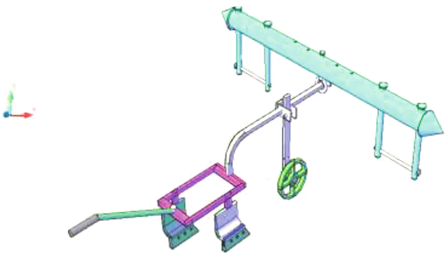

Fig. 4. 3rd alternative (conceptual design)

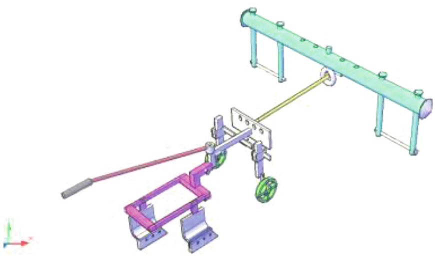

Fig. 5. 4th alternative (conceptual design)

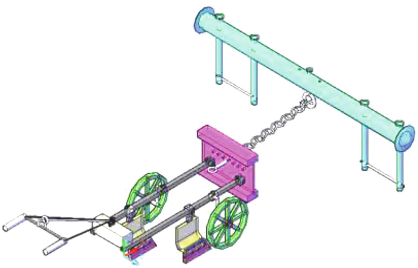

Fig. 6. 5th alternative (conceptual design)

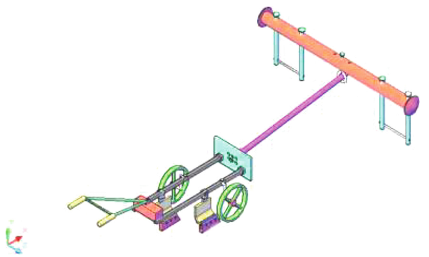

Fig. 7. 6th alternative (conceptual design)

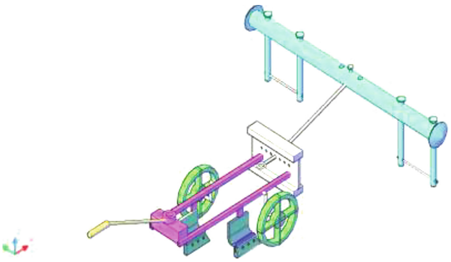

Fig. 8. 7th alternative (conceptual design)

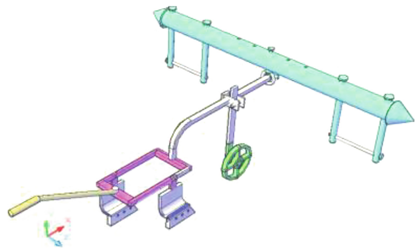

Fig. 9. 8th alternative (conceptual design)

3.2 Weighting Selection Parameters by Pairwise Comparison

Among many parameters, six critical parameters were selected for performance evaluation of the proposed conceptual designs. Due to the fact that animal drawn implements need to be light weight, ease for transportation and less draft power requirements. Moreover ease of operation, ease of implement to control and cutting depth evaluating criteria were also considered to assess the conceptual design. These parameters are designated by alphabetic letters for simplicity (A-F) (A = mass of implement, B = drafting power requirement, C = ease of operation, D = cutting depth, E = ease of implement control and F = ease of transportation).

Table 1. Relative weight assigning by pairwise comparison

Selection criteria	A	B	C	D	E	F	Row total	Relative weight
A	-	0	1	1	1	1	4	4/15 **(0.270)**
B	1	-	1	1	1	1	5	5/15 **(0.330)**
C	0	0	-	0	0	1	1	1/15 **(0.067)**
D	0	0	1	-	0	0	1	1/15 **(0.067)**
E	0	0	1	1	-	1	3	3/15 **(0.200)**
F	0	0	0	1	0	-	1	1/15 **(0.067)**
Total							15	1

Pairwise comparison of the conceptual design selection criteria indicated in Table 1, drafting power requirement with relative weight of (0.330) followed by mass of implement (0.270) and easy of implement control (0.2). Ease of operation, easy of transportation and cutting depth having equal relative weight of (0.067).

3.3 Selection Among Alternative Conceptual Design

Selection of evaluation scheme is important to select the optimum conceptual design. Eleven point scales were chosen to measure the overall performance of the proposed alternative conceptual designs.

Table 2. Selection of variants

Selection criteria	Relative weight	Alternative conceptual design							
		1	2	3	4	5	6	7	8
A	0.2670	**3** (0.80)	**2** (0.53)	**5** (1.34)	**5** (1.34)	**4** (1.07)	**5** (1.35)	**6** (1.60)	**5** (1.34)
B	0.3300	**4** (1.32)	**4** (1.32)	**4** (1.32)	**6** (1.98)	**6** (1.98)	**7** (2.31)	**7** (2.31)	**7** (2.31)
C	0.0667	**5** (0.34)	**6** (0.40)	**8** (0.53)	**7** (0.47)	**7** (0.47)	**7** (0.47)	**7** (0.46)	**6** (0.40)
D	0.0667	**10** (0.67)	**10** (0.67)	**4** (0.27)	**6** (0.40)	**7** (0.47)	**9** (0.60)	**7** (0.47)	**7** (0.47)
E	0.2000	**9** (1.80)	**9** (1.80)	**3** (0.60)	**3** (0.60)	**4** (0.80)	**5** (1.00)	**4** (0.80)	**4** (0.80)
F	0.0667	**2** (0.13)	**3** (0.20)	**8** (0.53)	**7** (0.47)	**6** (0.40)	**6** (0.40)	**6** (0.40)	**6** (0.40)
Total		5.057	4.921	4.59	5.249	5.182	6.112	6.046	5.317
Rank		6th	7th	8th	4th	5th	1st	2nd	3rd

Note: - Numbers outside the parenthesis written in the bold indicate that the given value out of 11 point and those inside the parenthesis is obtained by multiplying the relative weight of each criterion with 11 point scored value.

From the proposed alternative conceptual designs, alternative 6th is selected based on the highest point scored (Table 2), i.e. without seat to operator, two wheels, two handles and beam attachment (Fig. 7).

3.4 Working Principles of the Selected Conceptual Design

From the proposed alternative conceptual design, alternative 6 were selected because of higher scoring result when it is evaluated against the six measuring parameters. The implement working principle is similar to traditional Ard plough, except some parts of implement which are having cut adjustment in depth and width to fit for types of soil, types of land preparation and drafting force requirement (Fig. 10).

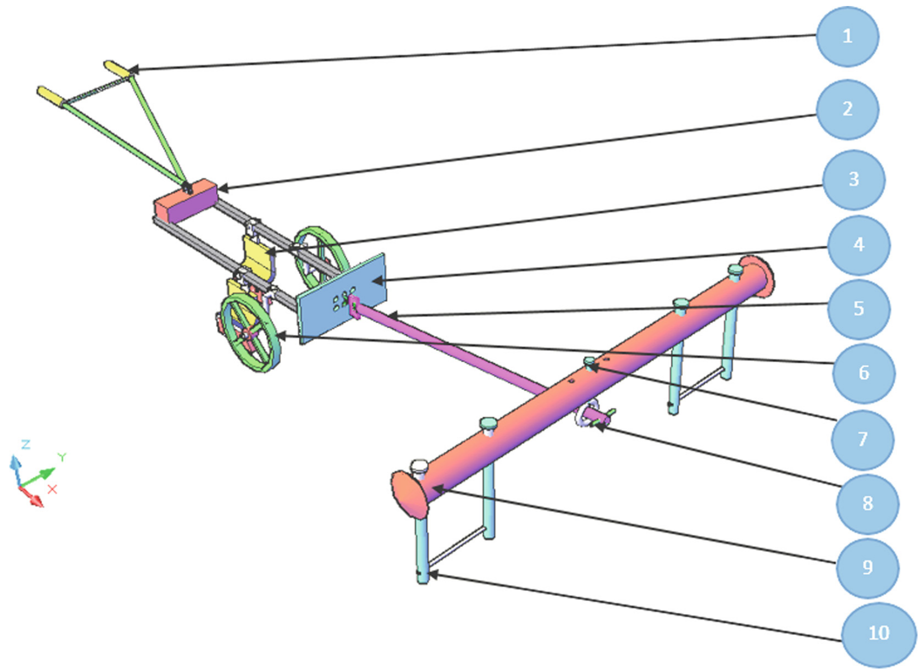

Fig. 10. Features of selected multiple mouldboard plough: (1) handling; (2) handling attachment; (3) mouldboard plough; (4) hitch; (5) beam; (6) wheel; (7) centring pin; (8) beam nose; (9) yoke; (10) neck holder.

4 Detail Design

The detail analysis of all the components and joint were done by taking in to consideration of the following conditions:-

- Pair of ox draft force (F_d) 870 N
- Operator force (F_o) 100–250 N
- The average working speed of ox is 0.63 m/s
- Soil moisture content 0–15%
- Rake angle 20^0
- Wood tensile strength along the grain 5.5 MPa and bearing strength of 2.2 MPa.

4.1 Design of Beam

A beam is a long wooden or metal piece, which connects the main body of the plough to the yoke. The material used as a beam in this research wood because of its light weight and low cost and locally available. Two common types of yokes are head yoke and neck yoke. The neck yoke is the commonly used by Ethiopian farmers.

Force Analysis Between Yoke and Beam

The pulling angle α_1 and α_2 are considered equal ($\alpha_1 = \alpha_2 = \alpha$) and the two animals pulling force F_1 and F_2 are also assumed to be equal ($F_1 = F_2 = F$). The pulling force F_b on the beam can be calculated from condition of equilibrium forces (Fig. 11).

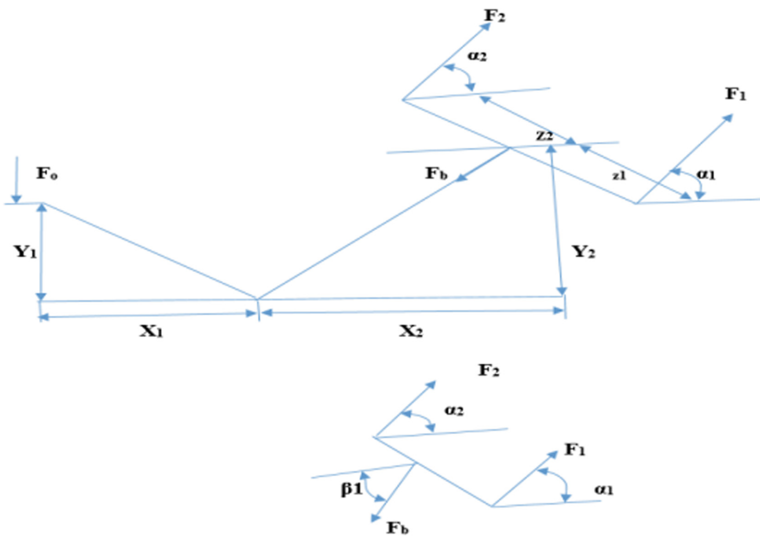

Fig. 11. Free body diagram of force analysis between yoke and beam

It is found from literature review and filed observation the height of animal's and traditional Ard plough beam length is between 1.0 m to 1.4 m and 2.5 m to 3.0 m, respectively. The average animal height of 1.2 m and the smallest beam length of 2.5 m were used for the design (Fig. 12). Using sine law (Eq. 1) the calculated angle is 15°.

$$\frac{\sin 90}{2500} = \frac{\sin \beta_1}{1200 - 550} \tag{1}$$
$$\beta_1 = \sin^{-1}(0.26) = 15^\circ$$

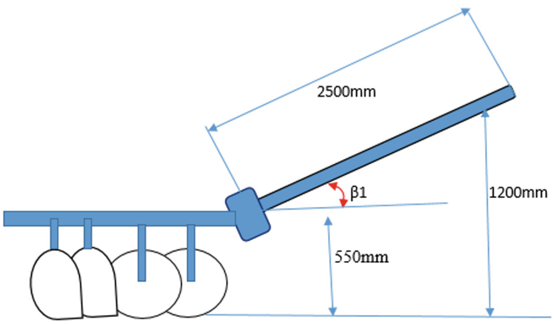

Fig. 12. Dimensions and layout of the beam attachments

The transferred pulling force from the two draught animals to the beam F_b and its angle of action β_1 can be given by Eqs. (2) and (3)

$$\sum F_x = F_1 \cos\alpha_1 + F_2 \cos\alpha_2 = F_b \cos\beta_1 \tag{2}$$

$$\sum F_y = F_1 \sin\alpha_1 + F_2 \sin\alpha_2 = F_B \sin\beta_1 \tag{3}$$

$$\begin{aligned} F_b &= \frac{F_1 \cos\alpha_1 + F_2 \cos\alpha_2}{\cos\beta_1} = \frac{F_1 \sin\alpha_1 + F_2 \sin\alpha_2}{\sin\beta_1} \\ \beta_1 &= \tan^{-1}\left\{\frac{F_1 \sin\alpha_1 + F_2 \sin\alpha_2}{F_1 \cos\alpha_1 + F_2 \cos\alpha_2}\right\} \end{aligned} \tag{4}$$

By considering β_1 and α are equal then F_b

$$F_d = F_b * \cos\beta_1 \tag{5}$$

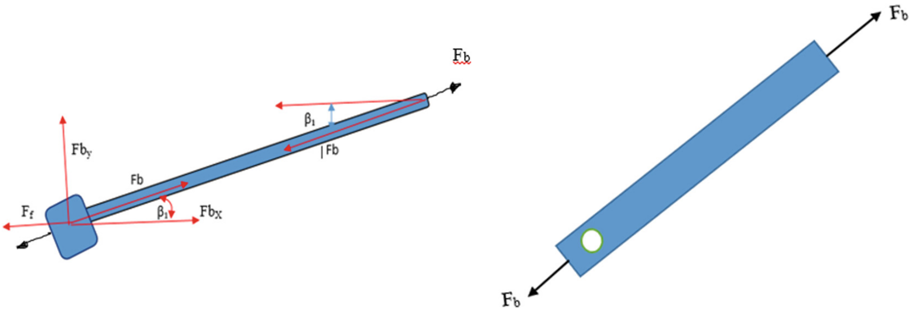

Fig. 13. Free body diagram of beam force

Where, β_1 = angle of the beam from the horizontal (Fig. 13).

$$\begin{aligned} F_d &= F_b \cos\beta_1 \\ F_b &= \mathbf{900\,N} \end{aligned}$$

$$\sum F_y = F_{by} = F_b \sin\beta_1 = 0 \tag{6}$$

$$\begin{aligned} \sum F_x &= F_{bx} = F_b \cos\beta_1 - F_f = 0 \\ F_f &= \mathbf{900\,N} \end{aligned} \tag{7}$$

Stress Analysis of Beam

1. *Tensile stress* (σ_t)
   When a body is subjected to two equal and opposite axial pulls (also called tensile load) then the stress induced at any section of the beam can be calculated as:

$$\sigma_t = F_b/A \tag{8}$$

Where, A = Cross-sectional area of the beam

$$A = \pi\frac{D^2}{4} - D * d = \frac{0.06^2}{4} - 0.06 * 0.01$$
$$A = 0.00223\,\mathrm{m}^2$$
$$\sigma_t = 403587.4\,\mathrm{N/m}^2 = 0.4036\,\mathrm{MPa}$$

The tensile stress induced (0.4036 MPa) on the beam due to the applied force is much less than that the material strength (5.5 MPa), hence the beam is safe for the tensile force acting on it.

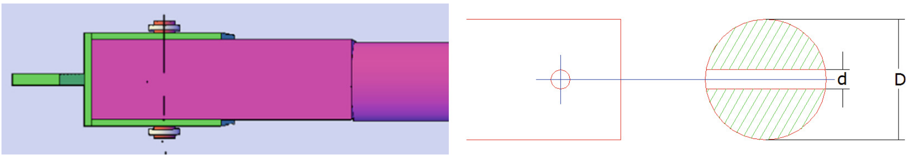

Fig. 14. Beam and its cross-sectional area

2. *Bearing stress* (σ_b)
   The induced bearing stress is a localised compressive stress at the surface of contact of the joint between the bolt and the sheet metal and calculated by Eq. 9.

$$\sigma_b = F_b/2td \tag{9}$$

Where t = thickens of sheet metal = 0.004 m

$$d = \text{diameter of bolt} = 0.01\,\mathrm{m}$$
$$\sigma_b = \frac{900\,\mathrm{N}}{2 * 0.004 * 0.01} = 1.2125\,\mathrm{MPa}$$

The bearing stress induce on the beam joint is less that 5.5 MPa, hence the beam is safe for the bearing force acting on it (Fig. 14).

4.2 Design of Hitch

A hitch part which connect the beam and the frame, for this research steel (Fe E 220) IS: 1570 (Part I)-1978 (Reaffirmed 1993) with ultimate tensile strength of 290 MPa and yield strength of 170 MPa is selected due to its low cost, availability and ease to carry the fabrication process (Fig. 15).

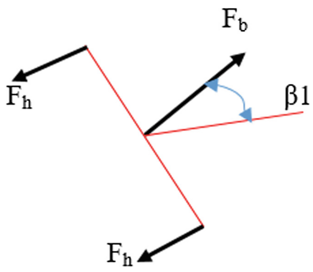

Fig. 15. Free body diagram of hitch

Force Analysis of the Hitch ($\mathbf{F_h}$)

$$\sum F_y = F_b \sin \beta_1 = 0 \tag{10}$$

$$\begin{aligned} \sum F_Z &= F_b \cos \beta_1 - 2F_h = 0 \\ 2F_h &= F_b \cos \beta_1 = 900\,\mathrm{N}\cos 15 = 870\,\mathrm{N} \\ \mathbf{F_h} &= \mathbf{435\,N} \end{aligned} \tag{11}$$

Stress Analysis of Hitch

1. *Tensile stress* (σ_t)

$$\begin{aligned} \sigma_t &= F_h/A \\ A &= 4 * t * b = 4 * 0.04\,\mathrm{m} * 0.06\,\mathrm{m} = 1.6 * 10^{-4}\,\mathrm{m}^2 \\ \sigma_t &= 435/1.6 * 10^{-4} = \mathbf{2.72\,MPa} \end{aligned}$$

2. *Shear stress* (τ)
   The hitch is connected with the frame by two bolts; hence it should withstand the developed shear stress.

$$\tau = \frac{F_h}{2A} \tag{12}$$

Where diameter of bolt 'd' is 0.01 m

$$A = \frac{\pi d^2}{4} = 7.86 * 10^{-5} m^2$$

$$\tau = 435/(2 * 7.86 * 10^{-5}) = \mathbf{2.77\,MPa}$$

3. *Bearing stress* (σ_b)

$$\sigma_b = \frac{F_h}{2td}$$

$$\sigma_b = \frac{435}{2 * 0.004 * 0.01} = \mathbf{5.44\,MPa}$$

The tensile stress, shear stress and bearing stress induce on the hitch are lower than the allowable stress limits, hence the hitch is safe to operate.

4.3 Design of Frame

Frame is connecting the wheels, hitch, handling and plough body. The frame is made of steel (Fe E 220) IS: 1570 (Part I)-1978 (Reaffirmed 1993) with ultimate tensile strength of 290 MPa and yield strength of 220 MPa.

Force Analysis of Frame

In order to calculate the force acting on the frame (Fig. 16), it is necessary to consider beam, yoke and hitch forces.

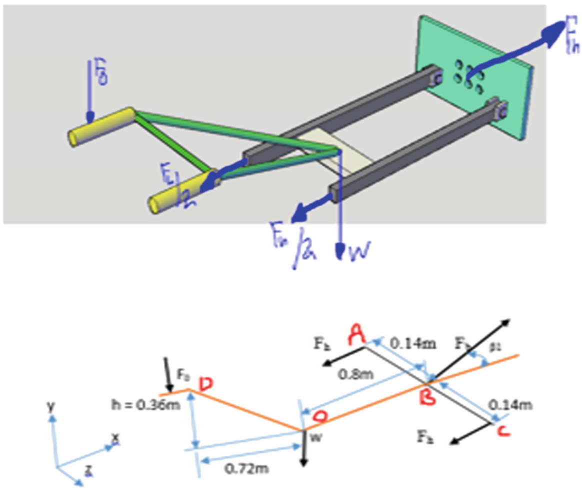

Fig. 16. Free body diagram and force analysis of the frame

The horizontal and vertical components of reaction force and moment on the frame and handle caused by the bolt at sections A, B, C and D were determined by considering equilibrium conditions.

$$\sum F_y = -2F_h + F_b \sin\beta_1 = 0 \tag{13}$$

From the above calculation F_b and β_1 are known then F_o is:-

$$\sum Mo = -F_o * 0.72 + 2F_h * 0.14 = 0$$
$$F_o = \frac{2Fh * 0.14}{0.72} = \frac{2 * 435 * 0.14}{0.72} = \mathbf{169.2\,N} \tag{14}$$

Tensile stress

$$\sigma_t = F_h/A$$
$$A = 4 * t * b = 4 * 0.04 * 0.06 = 1.6 * 10^{-4} m^2$$
$$\sigma_t = 435/1.6 * 10^{-4} = \mathbf{2.72\,MPa}$$

The tensile stress which is 2.72 MPa is less than the yield strength (170 MPa) of the material, so the frame structure is safe.

4.4 Design of Ploughshare

The share is attached to the frog by welding. It cuts a slice of soil horizontally and starts lifting it to the mouldboard. In ploughshare different forces and stresses are developed then it needs to have hard materials, high strength, and corrosion and wear resistant materials.

Force and Stress Analysis of Ploughshare
Where, V is gravitational force of the implement (excluding weights of the yoke and $\frac{1}{3}$ weights of the beam)

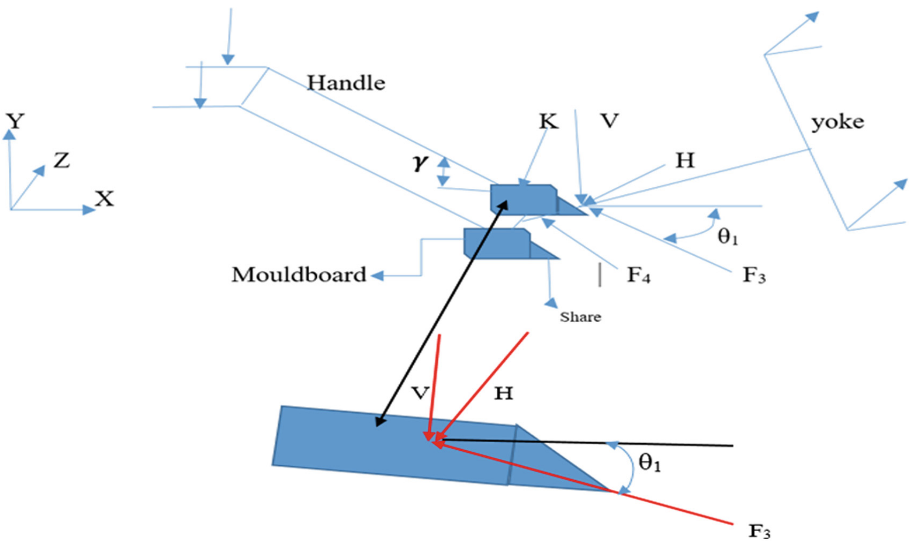

Fig. 17. Free body diagram of ploughshare

H is normal interfacial force of the ploughshare
F_3 is tangential interfacial force of the ploughshare.

From the free body diagram (Fig. 17) H is calculated by taking mass of implement 34 kg and gravitational force of the implement 333 N.

$$\sum F_y = 0 \tag{15}$$

$$\begin{aligned} & 2F\sin\alpha - F_o - H\sin(90-\theta_1) + F_3\sin\theta_1 - V = 0 \\ & H\sin(90-\theta_1) = H\,cos\,\theta_1 \\ & H = \frac{(2F\sin\alpha - Fo + F3\sin\theta 1 - V)}{\cos\theta 1} \end{aligned} \tag{16}$$

$$\sum F_x = 0 \tag{17}$$

$$\begin{aligned} & 2F\cos\alpha - F_3\cos\theta_1 - H\cos(90-\theta_1) = 0 \\ & H = \frac{2F\cos\alpha - F_3\cos\theta_1}{\sin\theta 1} \end{aligned} \tag{18}$$

F_3 can be calculated as:

$$\begin{aligned} & \frac{2F\sin\alpha - F_o + F_3\sin\theta_1 - V}{\cos\theta_1} = \frac{2F\cos\alpha - F3\cos\theta_1}{\sin\theta_1} \\ & F_3 = \frac{2F(\cos\alpha\cos\theta_1 - \sin\alpha\sin\theta_1) + V\sin\theta_1 + F_o\sin\theta_1}{\cos^2\theta 1 + \sin^2\theta 1} \\ & F_3 = 900(\cos 15\cos 20 - \sin 15\sin 20) + 333\sin 20 + 169.2\sin 20 \\ & F_3 = 737.24 + 113.9 + 57.87 = 909\,\text{N} \end{aligned} \tag{19}$$

Normal interfacial force of the ploughshare can be calculated as:

$$\begin{aligned} & H = \frac{2*450\ \cos 15 - 909\ \cos 20}{\sin 20} \\ & \mathbf{H = 44.30\,N} \end{aligned}$$

Area of penetration of ploughshare at the end of share 4 mm * 2 mm

$$\begin{aligned} & A = 8*10^{-6}\text{m}^2 \\ & \text{Force of penetration}(F_3)\ 909\,\text{N} \\ & \boldsymbol{\sigma} = \mathbf{F_3/A = 113.62\,MPa} \end{aligned}$$

The stress induced due to the penetration force on the ploughshare is less than the allowable limit; hence the part withstands the stress generated.

5 Results and Discussion

For the selected conceptual design of animal drawn multiple mouldboard plough, a detail design and analysis were performed and based on the result the prototype was fabricated for further test and modification. A prototype multiple mouldboard plough was fabricated at Bahir Dar Institute of Technology, Bahir Dar University (BIT-BDU) Mechanical Engineering workshops. The implement were tested in Burie and Gozamn districts at Nitosols and Vertisols in different soil moister content for primary tillage.

5.1 Results of Field Performance Test

In this research traditional Ard plough and multiple moldboard plough draft force requirement for the primary tillage was measured by modifying pocket balance to act as spring dynamometer.

Fig. 18. Multiple mouldboard plough spring dynamometer setup [Photo by the authors]

The field test was done on two types of plot (Nitosols and Vertisol) and the following result was found and tabulated in Tables 3 and 4.

5.2 Discussion

The conceptual design was made considering six important parameters (weight of implement, drafting power, ease of operation, cutting depth, implement control and transportation) and its relative weight of importance were prioritized by using pairwise ranking method. From the eight proposed alternative design options, the optimum design (Without seat to operator, two wheels, two handles and beam attachment) is selected fabrication and field test. The detail analysis of the selected concept was done and the parts are fabricated and assembled. Preliminary test was made on the farmer's

Fig. 19. Ard plough spring dynamometer setup [Photo by the authors]

Table 3. Ard (Maresha) plough primary tillage filed performance test result

Types of soils	Cutting depth [cm]	Cutting width [cm]	Draft [N]
Nitosols	14	16–18	883–922
Vertisols	15	18–19	883–902

Table 4. Multiple mouldboard plough primary tillage filed performance test result on Nitosols and Vertisol

Cutting depth [cm]	Soil types			
	Nitrosol		Vertisol	
	Cutting width [cm]	Draft [N]	Cutting width [cm]	Draft [N]
12	28	687–706	28	667–706
14	28	755–785	28	726–765
16	28	863–883	28	863–883
18	28	Difficult to pull	28	981

plot and necessary modification was carried out from the test result and the farmers' opinion. Further, field performance was studied on the new implement.

The test was performed on five plot of land for both Ard and multiple mouldboard plough for primary tillage. The data are recorded and analyzed. The results obtained during the test are depicted from Table 5, 6, 7 and 8. The farmers' opinion towards, the implement was positive with respect to its simplicity of harnessing, adjustment and operation. The newly modified farm implement at Nitosols and Vertisols, which showed satisfactory and good results, respectively.

Fig. 20. Multiple mouldboard plough filed performance test setup [Photo by the authors]

Also it is found that the mass of the multiple mouldboard plough is greater than the traditional Ard plough, but this does not affect the field performance due to the fact that the mass will be supported by the two wheels. The wheels also allow moving easily; hence the farmer could harness and pull by animals from home to the field yard.

The draft power requirement of primary tillage at Nitrisols of the multiple mouldboard plough was found less by 17.9% than the Ard plough, even though, the width of cut of the multiple mould board plough was wider by 65% (Table 5). Similarly, at Vertisols the draft force requirement for the multiple mouldboard plough was reduced by 19.7% than the Ard plough, though the width of cut was increased by 55.6% (Table 6). The draft force requirement of both Ard plough and multiple mouldboard plough is higher by 1.1% and 2.7% respectively at Nitrisols than Vertisols. The power requirement for both the ard plough and multiple mouldboard plough was slightly larger at Nitrisols than Vertisols (Tables 7 and 8). Multiple mouldboard plough width of cut and depth of cut can be adjusted to go well with the available draft animal for optimum field operation performance.

Table 5. Comparison of cutting width, depth, draft force of Ard plough and multiple mouldboard plough at Nitrisols

Types of plough	Cutting depth [cm]	Cutting width [cm]	Draft [N]
Ard plough	14	17	902
Multiple mouldboard plough	14	28	765

Table 6. Comparison of cutting width, depth, draft force of Ard plough and multiple mouldboard plough at Vertisols

Types of plough	Cutting depth [cm]	Cutting width [cm]	Draft [N]
Ard plough	14	18	892
Multiple mouldboard plough	14	28	745

Table 7. Comparison of drafting power requirement for Ard plough with multiple mouldboard plough in Nitosols

Types of plough	Draft [N]	Power [w]	Mass [kg]
Ard plough	883–912	0.92	27.5
Multiple mouldboard plough	755–785	0.78	33.8

Table 8. Comparison of drafting power requirement for Ard plough with multiple mouldboard plough in Vertisols

Types of plough	Draft [N]	Power [w]	Mass [kg]
Ard plough	883–902	0.91	27.5
Multiple mouldboard plough	755–785	0.76	33.8

6 Conclusions

The mass of the complete set of newly designed plough was found 33.8 kg and the Ard plough having an average of 27.5 kg. Though the newly designed mouldboard plough having larger mass but, due to the fact that the mass is not totally carried by the draft animal. The effects of the wheels also reduce the magnitude of the sliding friction. Hence multiple mouldboard plough demonstrated higher field operation performance than the Ard plough.

The field test result showed that, while comparing the Ard plough with multiple mouldboard plough at Nitrisols soil, the multiple mouldboard plough reduced the ploughing time by 39.3% in same cutting depth. While comparing Ard plough with that of multiple mouldboard plough at Vertisols soil fror primary tillage, the multiple mouldboard plough reduced the ploughing time by 35.7%. Multiple mouldboard plough also reduced drafting power 15.2% in Nitrisols and 16.5% Vertisols compared to Ard plough. The draft force requirement of Ard plough and multiple mouldboard plough was found higher by 1.1% and 2.7% respectively at Nitrisols than Vertisols. The newly designed multiple mouldboard plough, cut of width and depth can be adjusted to go well with the available draft animal for optimum field operation performance.

References

1. Solomon, G., et al.: Animal drawn tillage, the Ethiopian ard plough, maresha. a review. soil and tillage Res. **89**, 129–143 (2005)
2. Solomon, G., et al.: Design of the ethiopian ard plough using structural analysis validated with finite element analysis. J. Biosyst. Eng. **97**, 27–39 (2007)
3. Smolders, S.: Measurement of draught requirement of ard plough working in vertisol of Ethiopian highlands. Thesis for: Master of Science in bio-systems engineering (2006)
4. Loukanov, I.A., Uziak, J., Michálek, J.: Draught requirements of enamel coated animal drawn mouldboard plough. J. Res. Agri. Eng. **51**(2), 56–62 (2005)
5. Astatke, A., Mohammed-Saleem, M.A.: Experience with the use of a single ox for cultivation in the Ethiopian highlands. In: Animal Traction Network for Eastern and Southern Africa Workshop, Lusaka, Zambia (1992)
6. Hurst, K.: Engineering Design Principles, 1st edn. Elsevier, Amsterdam (1999)