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Research Article

Development and Performance Evaluation of Tractor-Drawn Chisel-Plow

Rebira Wirtu*, Wasihun Mitiku, Anane Gemeda

Jimma Agricultural Engineering Research Center, Oromia Agricultural Research Institute, Addis Ababa, Ethiopia

Abstract

Secondary tillage refers to tillage activities that come after primary tillage and are carried out to establish the right soil tilth for planting and seeding. Chisel plows are agricultural implements that farmers use to till the soil in preparation for planting crops. This plough can assist in breaking up ploughman and hardpan and lessen the effects of compaction. For no-till and low-till farming methods that aim to enhance erosion control and the advantages of maintaining organic matter and farming wastes on the soil surface throughout the year, a chisel plow is helpful. This study's goal was to create a tractor-drawn chisel plow for primary tillage and assess the device's effectiveness. A rectangular frame, a tyne, a chisel, a three-point hitch, and various connecting tools, including a washer, bolts, and nuts, made up the created tractor-drawn chisel plow. The depth, field capacity, field efficiency, clod mean weight diameter, bulk density, moisture content, and physical characteristics of the soil were all taken into account when evaluating the implement's performance. The field experiment was conducted at different depths of operation, 15cm. 20cm and 25cm, and tractor forward speed of 3, 5, and 7km/hr. The collected data were statistically analyzed using R software, and statistical differences in the effects of treatment means were tested at 5% levels of significance and separated using the least significant difference (LSD). From the obtained results, the draft requirement, the mean effective field capacity, field efficiency, fuel consumption, draft power, wheel slippage, and tillage performance index were 5.68 kN, 0.98 ha/hr.93.28%, 8.076l/ha, 9.38 kW, 11.33, and 2.69 at a tractor forward speed of 7 km/hr and 25 cm depth of operations. Based on the performance evaluation results, it is concluded that the developed tractor-drawn spike tooth harrow can be efficiently, effectively, and economically used by the end users.

Keywords

Development, Drawn, Chisel Plow, Plough, Tillage, Primary Tillage

1. Introduction

With 123 million people, Ethiopia is the second most populous country in Africa after Nigeria. Its economy is expected to be growing at one of the quickest rates in the continent, at 6.3 [1]. In this nation, agriculture is the main economic sector. Agriculture is a major contributor to the economy, accounting for almost 40% of GDP and 80% of exports [2, 3].

The process of preparing soil for crop cultivation is known as tillage. Due to its influence on soil environment conditions, aeration, weed control, soil moisture content, soil strength, and nutrient distribution, soil tillage is one of the most significant variables for plant growth [4].

Secondary tillage refers to tillage activities that are carried

*Correspondence: Rebira Wirtu (rebiraaga@gmail.com)

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out after primary tillage in order to provide the ideal soil tilth for planting and seeding [5]. Following main tillage operations, these lighter and finer activities are carried out on the soil [6]. Previous studies have shown that simple tillage tools, including cultivators and chisels, reduce fuel use, draft force, soil deterioration, and enhance yield [7]. To ascertain the efficacy of these kinds of basic soil tillage equipment, numerous research have been conducted on various topics, including single shearing elements, entire tools, and theoretical foundations [4]. Due to its excessive and detrimental impact on the physical, chemical, and biological properties of the soil, conventional tillage is gradually being replaced with vertical tillage methods [8].

Farmers use chisel plows as agricultural tools to till the soil before planting crops [9]. In terms of draft force, fuel consumption, soil disturbance, and soil roughness, the chisel plow—a crucial tillage equipment product in the vertical tillage system—performs better than the conventional moldboard and disc plows [10]. They differ from other kinds of plows due to their distinctive design. In order to properly design tillage equipment, choose the right tractor power, and identify the ideal operating conditions in tillage processes, draft force data is essential in tillage research. As a result, many experiments have been carried out to ascertain draft power and fuel consumption, either in the field or in soil bin circumstances [11]. A Numerous parameters, including soil type, soil moisture content and bulk density, depth and width of the cut, the form and geometry of the tine, tractor forward speed, prior treatments, and the cover crop, have been shown to have an impact on fuel, draft power, and energy consumption. The draw power of the tillage equipment with sweep type tine was raised by increasing the forward speed, cutting breadth, and working depth [12] When compared to other traditional tillage instruments, the chisel plow has the highest draft, field efficiency, and fuel consumption [13]. Compared to previous types of chisel plows with two and three rows, the modified chisel plow (4 rows Δ-shape) saved roughly 23–59 percent of power consumption and about 30–58 percent of energy requirements [14]. Chisel plows come in a variety of shank styles. Depending on the bulk density, soil type, and soil moisture level, these shank kinds can be employed in a variety of ways. Less energy is used by the spring-type shanks. The shearing resistance and, thus, the draft force were influenced by the cultivator's rake angle. Soil surface roughness is caused by irregularities in the soil surface. When it comes to sowing performance, seed emergence, erosion, infiltration, and overland flow, soil surface roughness is a crucial factor [15]. Soil texture, aggregate size, cover crops, tractor forward speed, tillage depth, and tillage tool all have an impact on soil roughness. Increasing the tractor's forward speed and operating depth disturbs more soil, which increases lateral soil movement and the degree of soil roughness. The narrow wing sweep and the normal sweep did not significantly alter the roughness of the soil, according to Pullen and Cowell. Because agricultural production tools and machinery interact with soil, modeling them can be challenging and complex. Modeling variables that do not have a linear relationship is particularly difficult. Because they disrupt less soil than traditional tillage techniques, chisel plows are mostly utilized in conservation tillage systems. Reduced soil erosion, better water infiltration, and improved soil structure are all advantages of utilizing a chisel plow. Conventional tillage, also known as traditional primary tillage, affects soil and crop productivity in both positive and negative ways [12]. Although it helps with weed control and seedbed preparation right away, its long-term effects frequently lead to soil erosion, deterioration, and loss of organic matter [16]. This study's goal was to create a tractor-drawn chisel plough and assess its effectiveness.

2. Materials and Methods

2.1. The study Area Description

The Oromia Agricultural Research Institute (OARI) in Ethiopia's Jimma Agricultural Engineering Research Center workshop produced the chisel plough. With an elevation of 1772 meters above sea level, the center is situated 354 kilometers from Addis Ababa at latitudes 7° 18′N and 8° 56′N and longitudes 35° 52′E and 37° 37′E.

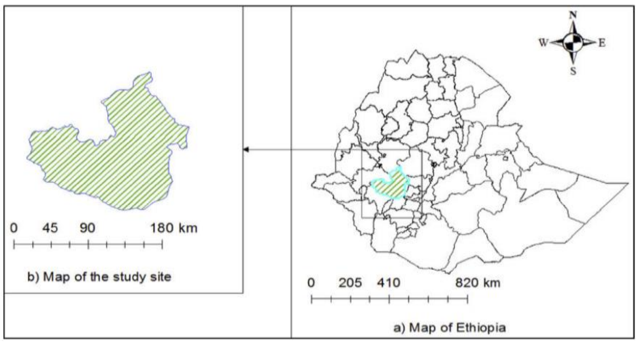

Figure 1. *Map of the study area.*

2.2. Material and Method

2.2.1. Materials

The components of the chisel plow are made from a variety of metals, including square pipe, bolts and nuts, flat iron, square shaft, etc.

2.2.2. Methods

(i). Power Unit Selection

The John Deere 5075M model 75 horsepower tractor manufactured in India was chosen as the motive engine for the chisel plow. The tractor's 2.9-liter, three-cylinder, turbo-charged engine was after-cooled. A 9x3 transmission, independent PTO, and a hydraulic lift capacity of up to 1800–2500 kg are among the main features. The tractor has an oil-immersed disk brake and power steering. The Hitch's total lifting capability was 2,578 kg (5,685 lbs); 2,993 kg was an option (6,600 lbs.).

Table 1. *Tools, materials and machines needed for the fabrication of the tie ridger.*

No	Machine/tool name	Function/purpose
	Welding machine	Welding metals
	Grinding machine	Grinding /cutting tool
	Pressing machine	Straight bended metal
	Metal hacksaw	cut square shaft
	Drilling machine	Hole/cell making
	Hammer	Used to strike the chisel
	Wrench	Tighten the bolt and nut
	Meter	Measure

(ii). Conceptual Design

The tractor-drawn chisel plough was developed basically to conduct deep tillage by loosening and aerating the soil without inverting the topsoil. Unlike a traditional moldboard plow, the chisel plow's tines fracture and break up compacted layers beneath the surface, leaving most of the crop residue on top. The functional components of the machine consist of the mainframe, shank, tine (tyne), hitch, and reversible chisel. The selection of materials for construction depends on strength, availability, durability, weight, and corrosion resistance. The tractor draw bar horsepower (DBHP), draught available (Df), and the number of the row (n) were calculated by Equation [16].

(iii). Design of the Mainframe

The mainframe was constructed from square pipe material and had low weight, strength, and dependability. The mainframe was connected to additional components of the ridge, such as the center driving wheel, furrow wing, bearings, etc. Additionally, the mainframe was equipped with three-point linkage attachments to connect to the power source. When choosing the frame's material, care has been taken to ensure that it is both lightweight and robust enough to support the applied load during field operations [17].

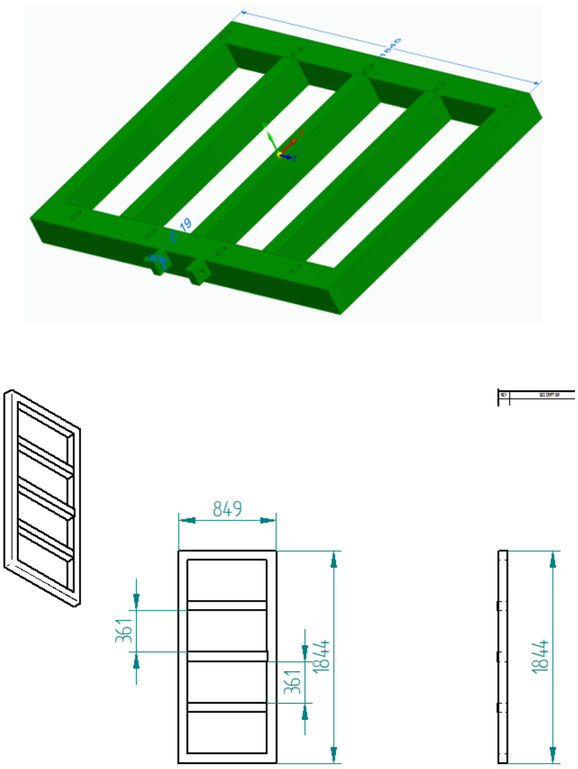

Figure 2. *Part design of Chisel plow Frame.*

Hitching System Design

The chisel ploughing machine was connected to the tractor using a three-point linkage system at the tractor's rear, operated via hydraulic control. Key geometric measurements, such as mast height, lower hitch point span, and the distance between the mast and the inch pin holes, were designed in compliance [17].

(iv). Design of Tine

The draught force acting at a height of h/9 from the bottom of the chisel plow, where h is the total length of the chisels and tine, is thought to have been between 50 and 100 kgf/tine on the thin tine.

To guarantee simple operation and appropriate machine balance, the standard will be set with a bending design. As advised, the narrow tine's (chisel's) maximum height was set at 20 cm [18]. Considering the draft force (in kN) that a tractor can use exerts on the tip of the chisel plough, which has a length of 43.5 cm bottom, the calculation is based on Equation below [19].

$$DBHP = \frac{D_f + v}{270}$$

Where: DBHP, Kw; D_f = Draft force, kg; V = Speed, km hr^{-1}.

Draft on tine was estimated using the following equation (Sharma and Mukesh, 2010):

$$D_e = A \times S_r \times FOS$$

Where: A = Cross-sectional area of the chisel (narrow tine), cm^2; S_r= Soil resistance, kg; FOS = Factor of safety; De= Theoretical draft on one tine, kg cm^{-2}.

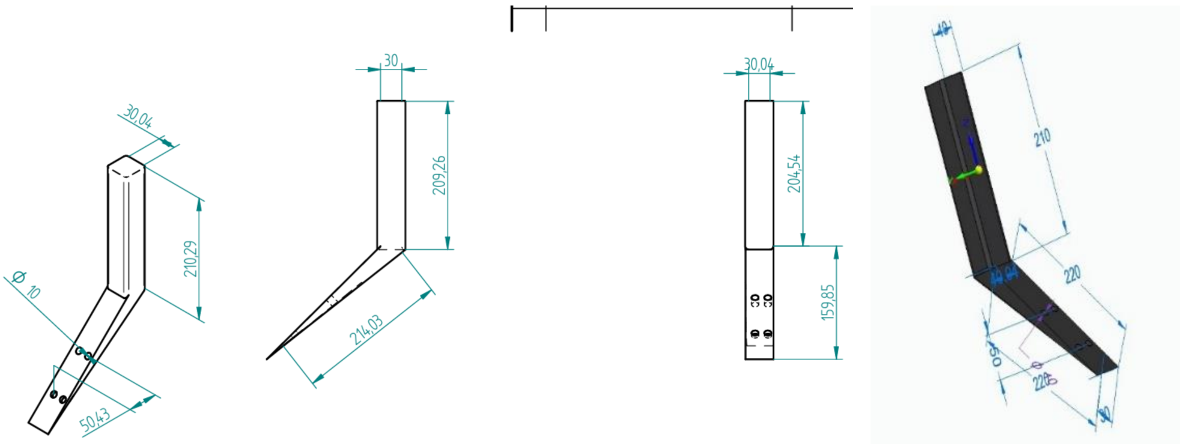

Figure 3. Part design of Chisel plow Tine.

Working speed

The working speed was estimated using Equation 11 below [17]

$$V = \frac{D}{ta}$$

Where: V = Working speed, m s-1; D = Distance of run, m; ta = Average time of each pass, s.

1) Design of ground tool (chisel and Shank)

A plow was needed, or the ground tool was used to maintain a consistent depth of action. The assumption provided by [19] was used to determine the sweep's thickness, width, and length.

Let L be the length of the thin tine's breast and b x h be the bare cross-section area in centimeters.

The ground tool's inclined portion is typically 21.4 cm long, with a radius of curvature of less than 12 cm. The ground tool (H-I.) had a minimum clearance length of 20 cm between the lower edge of the frame and the ground surface. The furrow opener's height was determined using the formula below.

$$H_T = a_{max} + H_I + \Delta H \quad = 10 + 43.5 + 20 = 73.5$$

Where: a_{max} = depth of tool, cm; H_I = length of ground tool, cm; ΔH = length of ground tool used for fastening with frame, cm. Load angle was determined by.

$$\tan\alpha = \frac{10}{30} = 0.33, \alpha = \tan^{-1}(0.33) = 18.26^{\circ}$$

Now the radius of curvature was determined as follows.

$$R_C = \frac{H_a - l_1 \sin\alpha}{\cos\alpha} \quad = \frac{20 - 22.5\sin 18.26}{\cos 18.25} = 28.3 \quad \text{cm}$$

Where: l_1= length of bthe restof the share, H_a= height of the first curvature point of the shank-plough from the point of cutting edge.

Because of the resistance of the soil, the chisel plough's cutting blade was initially exposed to bending. The furrow opener's axis of symmetry is where the horizontal soil resistance, F-X, acts. The following formula was used to get the average soil resistivity [20].

$$F_X \ = d \ \times \ w \times K_O \ \ = 30 \times 22.5 \times 0.25$$
$$= 168.75 \times 9.81 = 1655.4 \ \ N$$

Where; d = Effective working depth of narrow tine (cm); w = Working width of the narrow tine (cm); K_O = Specific soil resistance (kg/cm^2)

Table 2. Specific soil resistance at a depth of 15 cm.

S/N	Soil type	Specific resistance, kg/cm^2
1.	Light	0.12
2.	Medium	0.15
3.	Heavy	0.20
4.	Very heavy	0.25

Source; Dubey (2003)

The draft force exerted on the cutting blade was determined using the following equation.

$$D = K_O \times n \times w \times d = 0.25 \times 9 \times 22.5 \times 43.5 = 330.5N$$

Where, D = draft force, N; K_o= soil resistance, kg/cm^2; w= width of furrow opener, cm; d = depth of tine, cm; n= number of bottom chisel.

Hence factor of safety was assumed to be 3. Thus, total draught exerted on the reversible was calculated as follows.

$$D_t = 330.5N \times 3 = 991.5N$$

Where, D_t= total draft, N; D = draft, N; FOS = factor of safety; g = force due to gravity, m/s^2

$$D_i = \frac{\text{Draft (N)}}{\text{number of rows}} = \frac{991.5}{9} = 110 \text{ N}$$

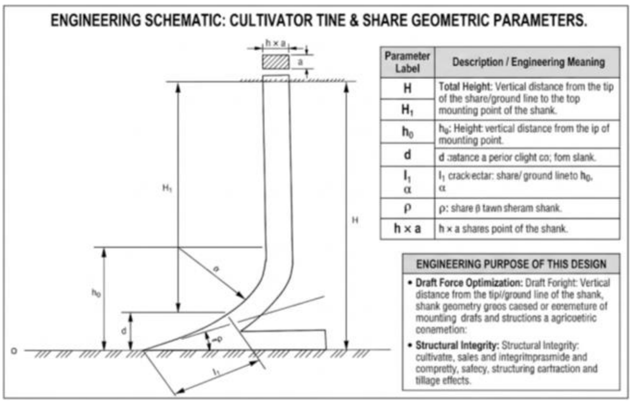

Figure 4. Schematic diagram of furrow opener.

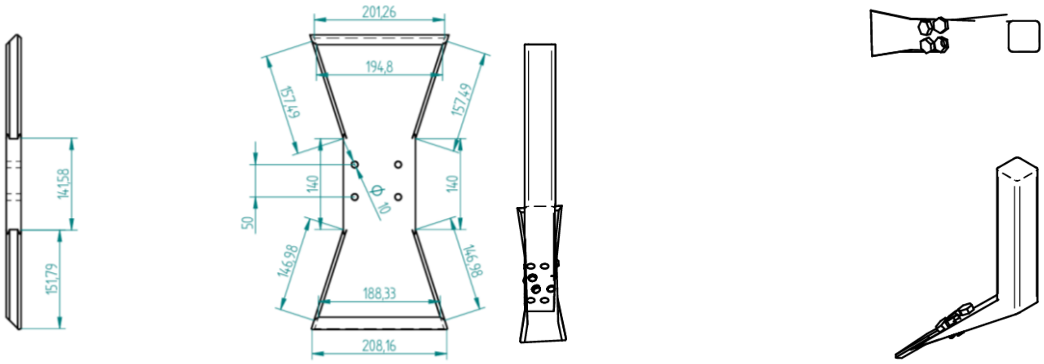

Figure 5. part design of Chisel plow Frame.

It was important to assess the weight of each component in order to estimate the weights on each portion of the chisel plow. As a result, the weights of the frame, reversible chisel, and tine or shank were calculated. The weight of the frame, three-point linkage unit, tine or shank, and reversible chisel were all included in the anticipated overall weight of the chisel plow. welding weights, bolts, nuts, etc. with a margin of two percent. Ultimately, 640.5 N was determined to be the chisel plough's entire weight.

2.2.3. Determination of Draft and Power Required

(i). Determination of Draft

The draft requirement of the tractor-primary chisel plow was estimated using factors related to the implement and type of soil [21].

Total working width = number of bottom x bottoms spacing=9 x 20 cm =180 cm

Cross-sectional area of furrows = Total working width of the narrow tine x depth of the furrow = 180cm x 43.50 cm = 0.7830 m^2

The maximum draft required to drive the narrow tine is calculated as follows.

$$D = C_{AC} \times S_R \times g \times FOS = 0.7830 \text{ cm}^2 \text{ x } 0.75 \text{ Kg/cm}^2 \text{ x } 9.81 \text{ m/s}^2 \text{ x } 1.5 = 8641\text{k N}$$

Where, D = Maximum draft; C_{AC}= Cross-section area of the furrows; S_R = maximum soil resistance; g = force due to gravity; FOS =the factor of safety

(ii). Determination of the Power

The power required to pull the designed implement was estimated as follows [22]

$$P_d = \frac{D \times S}{1000} = \frac{117.085 \times 0.60}{1000} = 70 \text{ KW} = 93.87 \text{ hp}$$

Where; P_d = power required to drive the implement; D = draft required to drive a furrow opener S = speed of operation (0.833 m/s)

The power required to operate the machine was calculated as follows.

$$P = \frac{\text{Power required to drive the implement}}{\text{Coefficient of friction}} = \frac{93.8}{0.85} = 110 \text{ hp}$$

Where: P = power required to operate the implement; D = draft requirement of the implement; S = forward speed of the tractor.

2.3. Description of the Machine and Components

The fabricated tractor-mounted row planter has components like a

Frame: The main structural component that holds all the other parts of the plough together. This frame made up of square pipe having 8cm x4 width and thickness respectively, and 85cm width and 184.5cm length dimension.

Beam: Connects the plough to the tractor or other draught source, allowing it to be pulled. It is made from flat iron having 4cmx8mm width and thickness, respectively, and 115cm in length and 58cm in height dimension.

Tyne: It is made from a square shaft having 4cmx4cm width, and thickness, respectively, and 43cm and 43cm height dimension. The upper portion of the tine was bolted to the frame. At the lower end of the tine, a chisel was provided to open up the soil during field operation. On the both sides of chisel opener on tine, hinge support was provided to attach the cutting chisel.

Chisel: The central element of the chisel plough, these are solid, chisel-shaped teeth that penetrate deep into the soil to break up compacted layers and loosen the earth without turning it over. It made from flat iron having 4cmx4mm width, and thickness respectively and 20 cm height dimension.

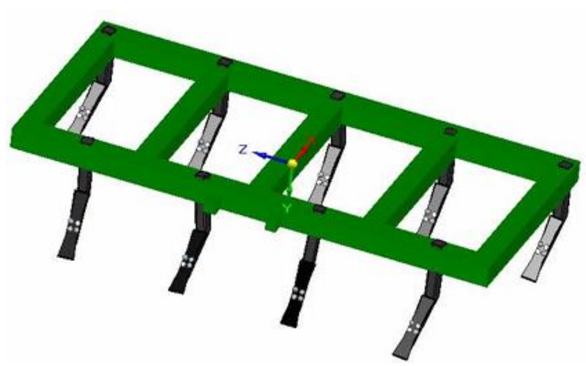

Figure 6. *Design of Chisel Plow Machine.*

2.4. Performance Evaluation of the Machine

To get experimental data about the overall performance and working capability of the implement in the field, a field performance evaluation was carried out. Time, speed, effective field capacity, theoretical field capacity, and field efficiency are among the parameters of field performance that are measured.

After the tractor was operating in the plot, a stopwatch was used to record the time. Productive time was added to turning time and other stop times to get the total time. The following formula was used to determine the plowing speed [23].

$$S = \frac{D}{t}$$

Where, S= plowing speed (km/h), D= plot length (km), t=time (h)

2.4.1. Soil Moisture

Before and after tillage, soil moisture samples were taken using a core sampler at three depth ranges: 0 to 10. After that, the soil samples and empty cans will be weighed and dried for 24 hours at 105 ℃. The soil samples were reweighed after being dried in the oven. The following formula was used to determine each sample's moisture content (MC percent) on a dry weight basis [24].

$$\text{moisture content}(\%)\text{dry basis} = \frac{W_w - W_d}{W_d} * 100$$

Where, W_w is the weight of wet soil (g) and W_d is the weight of dry soil (g)

2.4.2. Soil Bulk Density

The core method will be used to calculate the dry bulk density of the soil in the 0–10 cm range. A stainless-steel core sampler measuring 5 cm in diameter by 5 cm in height will be used to randomly collect three soil samples from each plot. After trimming the soil cores to precisely fit the cylinder's volume, they were oven-dried for a full day at 1050C. The mass of dry soil per unit volume of soil cores was used to calculate the dry bulk density. Using a core sampler (a cylindrical metal sampler), a soil core is sampled from the depth in its most natural state. The mass of solids and water content of the core are then determined by weighing the wet core and drying it to a constant weight in an oven [25]..

$$\text{Bulk density}\left(\frac{g}{cm^3}\right) = \frac{\text{weight of oven dry soil(g)}}{\text{volume of sample soil}(cm^3)}$$

2.4.3. Travel Reduction

Following the creation of a mark on the tractor drive wheel using colorful tapes, the tractor's advances under load and without load on the same surface were measured every ten rotations. The following formula was used to determine the speed reduction [26].

$$\text{Travel reduction} = \frac{M_2 - M_1}{M_2} \times 100$$

Where, M_2= a tractor drive wheel with no load (m), M_1 = tractor drive wheel with load (m).

2.4.4. Theoretical Field Capacity

This is dependent on the implement's speed and potential width. It is the rate of field coverage that was reached if the implement performed its job at 100% of its rated width [27].

$$\mathrm{TFC} = \frac{\mathrm{W \times S}}{10}$$

Where, TFC= Theoretical field capacity, ha/h; S= Speed of operation, km/h and W= Theoretical width of implement, m.

2.4.5. Effective Field Capacity

The actual pace at which the machine can operate is known as its effective field capacity. This includes ineffective practices like turning at the ends of the field to check how well a certain piece of equipment is working. Both the effective field capacity and the total time required to complete the process were calculated [28].

$$\mathrm{EFC} = \frac{\mathrm{A}}{\mathrm{T}}$$

Where, EFC = Effective field capacity, (ha/h); A = Actual area covered, (ha) and T= Total time required to cover the area, (hr)

2.4.6. Field Efficiency

Field efficiency is one of the most important criteria in determining the tillage implement performance. It was calculated using the formula below [27].

$$\text{Field efficiency (\%)} = \frac{\mathrm{EFC}}{\mathrm{TFC}} \times 100$$

2.4.7. Fuel Consumption

The top-fill approach was used to calculate fuel usage. The petrol tank was filled before the test. The fuel consumption for the duration of the test is the amount of fuel required to refill the tank after the test. Using the formula below, the fuel consumption in liters per hour was determined using the observed data [30].

$\mathrm{Fc} = \frac{\mathrm{f_r}}{\mathrm{t}}$ where : Fc = fuel consumption (l/hr); $\mathrm{f_r}$ = Refilled quantity of fuel (l); t =total time taken (hr).

2.4.8. Mean Weight Diameter

Wet sieving, a technique that involves wetting and oscillating soil in water before subjecting it to a series of sieves, is used to calculate the mean weight diameter (MWD) of soil aggregates. The MWD is determined by adding the products of the weight of the soil on each sieve and the mean diameter of the neighboring sieve sizes. This technique divides aggregates according to size. The stability of the soil aggregate is measured by this value.

The mean weight diameter is calculated by using the following equation [31]:

$$MWD = \sum_{i=1}^{n} xi \times wi$$

Where, xi is the mean diameter of the i-th aggregate size class and wi =is the weight proportion of that class.

2.4.9. Volume of Soil Handled

The effective field capacity was multiplied by the depth of operation to estimate the amount of soil handled, as indicated by the equation below. As a result, the amount of soil handled in a certain amount of time may be written as [29]:

$$\mathrm{V_{sh}} = \mathrm{EFC} \times \mathrm{D_o} \times 1000$$

Where, EFC =is effective field capacity, $\mathrm{D_o}$= depth of operation,$\mathrm{V_{sh}}$= volume of soil handled.

2.4.10. Tillage Performance Index

The Tillage Performance Index (TPI), a comprehensive metric used to assess the efficacy of tillage operations, is thought to be inversely proportional to fuel energy (Fe) and mass weight diameter (MWD) and directly proportional to the volume of soil handled per unit time (Vs) and soil inversion (SI) [26]:

$$TPI = \frac{Vs}{MWD \times F_e}$$

3. Results and Discussion

3.1. Moisture Content of the Soil

To determine the moisture content, three soil samples were randomly obtained between 0 and 25 cm below the earth's surface. Table 1 shows the average moisture content. The oven-dry mass per unit volume of soil is known as bulk density. The core cutter method was used to measure it. Using a core cutter, soil samples were collected at random in the field. The core method was used to calculate the soil dry bulk density in the 0–10 cm range. A stainless-steel core sampler measuring 5 cm in diameter and 5 cm in height was used to randomly collect three soil samples per plot.

The bulk density during the route was determined to be 1.328t/m^3, with an average moisture content of 16%.

***Table 3**. Moisture content of the soil.*

Observation	Weight of soil sample before oven (g)	Weight of soil after oven dried (g)	Soil moisture content (d.b%)	Volume of core sampler (cm^3)	Bulk density (gcm^{-3})
1	742	700	16.73	491	1.06
2	756	701	20.75	491	1.07
3	726	681	19.14	491	1.066
Average	741.3	694	18.87	491	1.065
S.D	15.01	11.27	2.023		0.00503

According to Table 3, the moisture content was determined to be 16.73 percent, 20.75 percent, and 19.14 percent at three distinct locations. The experimental field had an average moisture content of 18.87 percent. A core sampler was used to determine the bulk density of the soil. The bulk densities of the soil were determined to be 1.06 g cm^{-3}, 1.07 g cm^{-3}, and 1.066 gmc^{-3} (Table 3). The investigated plot's average bulk density was determined to be 1.065 g cm^{-3}.

***Table 4**. Interaction effect of depth and speed of operation on performance parameters.*

Depth	Speed	DR (KN)	FC (l/ha)	TFC (ha/hr)	WS (%)	EFC (ha/hr)
	S1	4.03^{i}	4.88^{i}	0.52^{c}	6.88^{i}	0.62^{g}
D_1	S2	4.06^{f}	6.51^{f}	0.99^{b}	9.25^{f}	0.91^{d}
	S3	5.2^{c}	7.41^{c}	1.18^{a}	9.98^{c}	0.98^{a}
	S1	3.99^{h}	5.15^{h}	0.52^{c}	6.97h	0.60^{h}
D_2	S2	4.89^{e}	7.08^{e}	0.99^{b}	8.85^{e}	0.92^{e}
	S3	5.45^{b}	8.22^{b}	1.18^{a}	10.13^{b}	0.96^{b}
	S1	3.63^{g}	6.21^{g}	0.52^{c}	7.54^{g}	0.44^{i}
D_3	S2	4.67^{d}	7.35^{d}	0.99^{b}	9.48^{d}	0.88^{f}
	S3	5.68^{a}	8.76^{a}	1.18^{a}	11.33^{a}	0.94^{c}
CV (%)		2.49	1.99	4.65	2.57	5.04
LSD (5%)		0.41	0.40	0.34	0.52	0.03

Where, DR= draft, FC= fuel consumed, TFC = theoretical field capacity, EFC= effective field capacity D_1=15 cm, D_2=20 cm D_3=25, S_1=3 km/hr, S_2=5 km/hr, S_3=7 km/hr, CV=coefficient of variation, LSD = least significance difference

3.2. Effect of Depth and Tractor Forward Speed on a Draft

The lowest draft value of 4.03 was recorded at 15 cm depth and 3 km/h tractor forward speed, while the greatest draft of 5.68 kN was obtained for 25 cm depth and 7 km/h tractor forward speed. As can be seen in the above table, the draft rose along with the tractor's forward speed and depth of operation. ANOVA revealed that both tractor forward speed and depth of operations had a significant ($p<0.05$) impact on the draft requirement. The combination of depth and forward speed also had a significant ($p<0.05$) effect on the draft need. The draft requirement of the implement increased with the tractor's forward speed and depth of operation. The reason could be that deeper activities and higher tractor advance speeds require more power than lower ones. This observation validated Okoko et alfindings.'s (2018).

3.3. Effect of Depth and Tractor Forward Speed on Theoretical Field Capacity

Table 5 demonstrates that the maximum theoretical field capacity (1.18 ha/hr) was acquired at a tractor forward speed of

7 km/hr for all depths of operation, while the minimum theoretical field capacity (0.52 ha/hr) was reached at all depths of operation and at a tractor forward speed of 3 km/hr. ANOVA showed that tractor forward speed had a significant impact on theoretical field capacity ($p<0.05$), whereas depth of operations and the combination of depth of operations and tractor forward speed had no significant impact ($p>0.05$). Table 3 demonstrates that theoretical field capacity grew in tandem with tractor forward speed. The reason could be the independence of theoretical field capacity from field conditions and operator efficiency. This observation was similar to Al-Outcome. Shamiry's (2020).

3.4. Effect of Depth and Tractor Forward Speed on Effective Field Capacity

The maximum effective field capacity (0.98 ha/hr) was achieved at a tractor forward speed of 7 km/h and a depth of operations of 15 cm. This might be as a result of a minimum depth that enables faster operation. The minimal effective field capacity of 0.44 ha/hr was achieved at a depth of operations of 20 cm and a tractor forward speed of 3 km/h. This could be due to deeper procedures and a delay at the turning point. ANOVA showed that tractor forward speed, depth of operations, and their combination had a significant ($p<0.05$) impact on effective field capacity. There was a declining trend in effective field capacity as the depth of activities grew. It has been demonstrated that increasing tractor forward speed while maintaining a fixed depth of operation increases effective field capacity. The explanation can be that, compared to a lower tractor forward speed, a higher tractor forward speed enables a shorter time delay and a larger area covered in a shorter amount of time. This result was in line with the findings of Al-Shamiry and Mohammed (2015). (2020).

3.5. Effect of Depth and Tractor Forward Speed on Wheel Slippage

The maximum wheel slippage (11.33%) was achieved at a tractor forward speed of 7 km/h and a depth of operation of 25 cm. The tractor operating at a depth of 15 cm and traveling at 3 km/h had the lowest percentage of wheel slippage (6.88 percent). Wheel slippage was significantly ($p<0.05$) impacted by tractor forward speed, depth of operation, and their combination, according to an ANOVA. Table 3 demonstrated that when tractor forward speed and depth of operation increased, wheel slippage worsened. The rolling resistance of the tractor tires and the rolling action of the implement, which opposes the rotation movement for the increased tractor forward speed and depth of operations, could be the reason of the negative rise in wheel slippage. This finding was consistent with Kudabo and Gabdamosi's findings.

3.6. Effect of Depth and Tractor Forward Speed on Fuel Consumption

The lowest fuel consumption (5.72 l/ha) was noted at a depth of operation of 10 cm and a tractor forward speed of 3 km/h. The maximum fuel consumption (8.02 l/ha) was attained at a depth of operation of 20 cm and a tractor forward speed of 7 km/h. Deeper actions may be the cause of this. Fuel consumption was considerably ($p<0.05$) impacted by tractor forward speed and depth of activities, according to an ANOVA. The combination of speed and depth of operations also had a significant ($p<0.05$) effect on fuel usage. Table 3 demonstrates that fuel usage rose in tandem with tractor forward speed and depth of operation. This could be due to the fact that tractors with higher forward speeds experience less time delay than those with lower forward speeds. This outcome was consistent with the findings of Kudabo and Gabdamosi (2012) and Al-Shamiry (2020).

Table 5. *Interaction effect of operation depth and speed on performance parameters.*

Implement	Speed	FE (%)	PO (kW)	TPI
	S1	87.2^{g}	6.33^{i}	1.20^{i}
D_1	S2	90.14^{d}	7.64^{f}	1.720^{f}
	S3	93.28^{a}	8.20^{c}	2.89^{c}
	S1	85.06^{h}	6.77^{h}	2.00^{h}
D_2	S2	89.37^{e}	7.57^{e}	2.31^{e}
	S3	92.67^{b}	8.49^{b}	2.91^{b}
	S1	84.00^{i}	7.24^{g}	1.55^{g}
D_3	S2	88.10^{f}	8.00^{d}	2.56^{d}
	S3	91.32^{c}	9.38^{a}	2.97^{a}
CV (%)		0.78	2.89	0.45

Implement	Speed	FE (%)	PO (kW)	TPI
LSD (5%)		1.16	0.52	0.21

Where, PO=power, SI= soil inversion, VS=volume of soil handled, CMD = clod mean diameter, FE=field efficiency, D_1=10 cm, D_2=15 cm, D_3=20 cm, S_1=3 km/hr, S_2= 5 km/hr, S_3=7 km/hr, CV=coefficient of variation, LSD = least significance difference, SEM = standard error of the mean, values are mean ± SD and Mean values followed by the same letter in a column are not significantly different at 5% level of significance

3.7. Effect of Depth and Tractor Forward Speed on Field Efficiency

The maximum effective field capacity of 93.28 ha/hr was achieved at a maximum depth of operations of 25 cm and a maximum tractor forward speed of 7 km/h. This might be as a result of a minimum depth that enables faster operation. The minimal effective field capacity of 0.44 ha/hr was achieved at a depth of operations of 20 cm and a tractor forward speed of 3 km/h. This could be due to deeper procedures and a delay at the turning point. ANOVA showed that tractor forward speed, depth of operations, and their combination had a significant ($p<0.05$) impact on effective field capacity. There was a declining trend in effective field capacity as the depth of activities grew. It has been demonstrated that increasing tractor forward speed while maintaining a fixed depth of operation increases effective field capacity. The explanation can be that, compared to a lower tractor forward speed, a higher tractor forward speed enables a shorter time delay and a larger area covered in a shorter amount of time. This result was in line with the findings of Al-Shamiry and Mohammed (2015). (2020).

3.8. Tillage Performance Index

When the tractor's forward speed and depth of operation increased from 3 km/h to 7 km/h and from 15 cm to 25 cm, respectively, the tillage performance index rose from 1.20 to 2.97. The depth of operations, tractor forward speed, and their combination significantly affected the tillage performance index, according to the ANOVA table. The tillage performance index rose in tandem with tractor forward speed and depth of operation.

3.9. Cost Estimation of Machine

Table 6. *Cost estimation for chisel plow machine.*

No.	Cost variables	Summary
A	Raw materials cost	24000ETB
B	Manufacturing process labor cost	8000 ETB
C	Manufacturing process labor	9000 ETB
D	Machine wastages 2.5%	600 ETB
E	Overhead cost 5% (C+D)	9600ETB
F	Profit 10% (A+B+C+D+E)	5120 ETB
G	Sell tax 15%	8448 ETB
	Selling price	64768 ETB

4. Conclusions

A randomized whole block design was used for the experiment (RCBD). There are two treatments in the experiment (depth of operation and tractor forward speed). There were three depth levels: 15, 20, and 25 cm. There are three replications for each of the three speed levels: 3, 5, and 7 km/h.

At a depth of operations of 25 cm and a tractor forward speed of 7 km/h, the maximum draft was achieved. The tractor forward speed of 3 km/h and a minimal draft of 15 cm were noted. ANOVA showed that the draft needed was significantly impacted ($p<0.05$) by both the tractor's forward speed and depth of operations.

For every depth of operation, the maximum theoretical field capacity (1.18 ha/hr.) was found at a maximum tractor forward speed, while the lowest theoretical field capacity (0.52 ha/hr.) was found at a minimum tractor forward speed.

ANOVA revealed that while depth of operations and the interaction between depth of operations and tractor forward speed had no significant influence ($p>0.05$) on theoretical field capacity, tractor forward speed had a significant effect ($p<0.05$).

At the minimum operating depth of 15 cm and the maximum tractor forward speed of 7 km/h, the maximum effective field capacity of 0.98 ha/hr was measured. At the minimum tractor forward speed of 3 km/h and the maximum operating depth of 25 cm, the lowest effective field capacity of 0.44 ha/hr was achieved.

Effective field capacity was significantly impacted ($p<0.05$) by depth of operations, tractor forward speed, and their interaction, according to an ANOVA. At a constant depth of operation, an increase in tractor forward speed resulted in an increase in effective field capacity.

At the maximum forward speed of the tractor (7 km/h) and the maximum depth of operation, the highest wheel slippage (11.33 percent) was observed (25 cm). At the lowest tractor forward speed of 3 km/h and the lowest operating depth, the least amount of wheel slippage (6.88 percent) was noted (10 cm).

Wheel slippage was significantly impacted ($p<0.05$) by depth of operation, tractor forward speed, and their combination, according to an ANOVA. Table 3 demonstrated that as tractor forward speed and depth of operation rose, wheel slippage decreased.

5. Recommendation

1) Based on performance evaluations, the created spike teeth chisel plow can be effectively tested on farms. However, the following issue must be fixed in order to make the prototype flexible and available to farmers.
2) Evaluating an impalement on different soil types and conditions is crucial.
3) Some more weight and improvements, like wheel attachment and size increase, should be done for further improvement.

Abbreviations

RCBD	Randomized Complete Block Design
TPI	Tillage Performance Index
MWD	Mean Weight Diameter

Author Contributions

Rebira Wirtu: Conceptualization, writing- Original draft
Wasihun Mitiku: Data curation, Methodology,
Anane Gemeda: Data analysis, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] "A Design, Development and Performance Evaluation of Tractor Drawn Tie Ridger | Agricultural Engineering International: CIGR Journal." https://cigrjournal.org/index.php/Ejounral/article/view/9377 (December 14, 2025).

[2] A, Hammad E, Idris S A, and E A Hammad. 2013. "Greener Journal of Agricultural Sciences Performance of Conventional and Locally Fabricated Chisel Plows in Canefields of the Sudanese Sugar Company." 3(7): 598–605. https://doi.org/10.15580/GJAS.2013.3.070913714

[3] Anil Kumar, A., Ch Ramulu, B Laxman, and G Kishore. 2017. "Design and Development of Groundnut Planter for Power Weeder." 6(10): 3516–28. https://doi.org/int.j.curr.microbiol

[4] Bhattacharya, Priya, Pragati Pramanik Maity, Mrinmoy Ray, and Nilimesh Mridha. 2021. "Prediction of Mean Weight Diameter of Soil Using Machine Learning Approaches." *Agronomy Journal* 113(2): 1303–16. https://doi.org/10.1002/AGJ2.20469

[5] Blake, George R., and K. H. Hartge. 2018. "Bulk Density." *Methods of Soil Analysis, Part 1: Physical and Mineralogical Methods*: 363–75. https://doi.org/10.2136/SSSABOOKSER5.1.2ED.C13;CTYPE:STRING:BOOK

[6] Bralts, V. F. 1986. "Field Performance and Evaluation." *Developments in Agricultural Engineering* 9(C): 216–40. https://doi.org/10.1016/B978-0-444-42615-4.50014-X

[7] "'Effect of Tillage Implements and Operating Speeds on Soil Physical Pro' by MUSTAFA GÖKALP BOYDAŞ and NİHAT TURGUT." https://journals.tubitak.gov.tr/agriculture/vol31/iss6/6/ (December 13, 2025)

[8] "Introduction to Agricultural Engineering - Abhay Kumar Sinha - Google Books." https://books.google.com.et/books?hl=en&lr=&id=lkBCEQAAQBAJ&oi=fnd&pg=PP1&dq=The+tractor-drawn

[9] Jishna P, By K. "Design And Performance Evaluation of a Mini Tractor Mounted Clod Crusher."

[10] Kharmanda, G, M-H Ibrahim, A Abo Al-Kheer, F Guerin, and A El-Hami. 2014. "Reliability-Based Design Optimization of Shank Chisel Plough Using Optimum Safety Factor Strategy." https://doi.org/10.1016/j.compag.2014.09.001

[11] Kishore Kumar, G, D Anil Kumar, and Y Dileep Sean. 2017. "Performance Evaluation of Power Weeder Under Dry and Wet Land Conditions."

[12] Komiyama, Akira, Sasitorn Poungparn, and Shogo Kato. 2005. "Common Allometric Equations for Estimating the Tree Weight of Mangroves." *Journal of Tropical Ecology* 21(4): 471–77. https://doi.org/10.1017/S0266467405002476

[13] Li, B ;, J ; Pan, Y ; Li, K ; Ni, W ; Huang, H ; Jiang, F Liu, et al. 2023. "Optimization Method of Speed Ratio for Power-Shift Transmission of Agricultural Tractor." *Machines 2023, Vol. 11, Page 438* 11(4): 438. https://doi.org/10.3390/MACHINES11040438

[14] Manuwa, S. I. 2009. "Performance Evaluation of Tillage Tines Operating under Different Depths in a Sandy Clay Loam Soil." *Soil and Tillage Research* 103(2): 399–405. https://doi.org/10.1016/J.STILL.2008.12.004

[15] Mehrara, Mohsen, and Javad Baghbanpour. "The Contribution of Industry and Agriculture Exports to Economic Growth: The Case of Developing Countries." https://doi.org/www.worldscientificnews.com (December 13, 2025)

[16] Nicolle, Hervé, Juan-David Sempere, Lisa Pfister, and Rosa Ojwang. "Decisions to Stay and Migrate in Algeria, Ethiopia and Nigeria." https://hal.parisnanterre.fr/hal-04574599v1 (December 13, 2025)

[17] Nielsen, S. Suzanne. 2017. "Moisture Content Determination." 105–15. https://doi.org/10.1007/978-3-319-44127-6_10

[18] Prem, Manjeet, R Swarnkar, D K Vyas, S J Pargi, and B C Khodifad. 2016. "Combined Tillage Tools: A Review." *Current Agriculture Research Journal* 4(2): 179–85. https://doi.org/10.12944/CARJ.4.2.07

[19] Ranjbarian, Saeed, Mohammad Askari, and Javad Jannatkhah. 2017. "Performance of Tractor and Tillage Implements in Clay Soil." *Journal of the Saudi Society of Agricultural Sciences* 16(2): 154–62. https://doi.org/10.1016/J.JSSAS.2015.05.003

[20] RENOLL ES. 1970. "Method for Predicting Field-Machinery Efficiency and Capacity." *Transactions of the ASAE* 13(4): 448–49. https://doi.org/10.13031/2013.38632

[21] USAID. 2020. "Ethiopia Country Profile." Humanitarian Crisis and Response in the Horn of Africa: 137–48.

[22] world bank. 2020. "The Ethiopian Economy." Regional Development Poles and the Transformation of African Economies (November): 88–117. https://doi.org/10.4324/9781003024804-5

[23] Zhang, Xiaofei. "Design Theory and Performance Analysis of Electric Tractor Drive System." www.ijert.org (December 14, 2025).

[24] Wang C, Yan Z, Wang Z, et al. Subsoil tillage promotes root and shoot growth of rapeseed in paddy fields and dryland in Yangtze River Basin soils. Eur J Agron. 2021; 130. https://doi.org/10.1016/j.eja.2021.126351

[25] Panagos P, De Rosa D, Liakos L, Labouyrie M, Borrelli P, Ballabio C. Soil bulk density assessment in Europe. Agric Ecosyst Environ. 2024; 364. https://doi.org/10.1016/j.agee.2024.108907

[26] Raheman H, Sarkar P. Combination Tillage Implements. Tillage Mach Act Comb. Published online 2024: 129-157. https://doi.org/10.1007/978-981-99-6331-7_6

[27] Ajit K. Srivastava, Carroll E. Goering, Roger P. Rohrbach, Dennis R. Buckmaster. Engineering Principles of Agricultural Machines, Second Edition. Eng Princ Agric Mach Second Ed. Published online November 1, 2013. https://doi.org/10.13031/EPAM.2013

[28] Berhe FT, Fanta A, Alamirew T, Melesse AM. The effect of tillage practices on grain yield and water use efficiency. CATENA. 2013; 100: 128-138. https://doi.org/10.1016/J.CATENA.2012.08.001

[29] Cassel DK, Nielsen DR. Field Capacity and Available Water Capacity. Methods Soil Anal Part 1 Phys Mineral Methods. Published online September 11, 2018: 901-926. https://doi.org/10.2136/SSSABOOKSER5.1.2ED.C36

[30] Rasool S, Raheman H. Improving the tractive performance of walking tractors using rubber tracks. Biosyst Eng. 2018; 167: 51-62. https://doi.org/10.1016/j.biosystemseng.2017.12.013

[31] Janulevičius A, Damanauskas V. Validation of relationships between tractor performance indicators, engine control unit data and field dimensions during tillage. Mech Syst Signal Process. 2023; 191: 110201. https://doi.org/10.1016/J.YMSSP.2023.110201