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Design and Optimization of a Single-Axle Power Tiller for Small and Marginal Farmers in East Africa, Particularly in Southern Ethiopia

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ABSTRACT

Traditional tillage methods employed by hillside farmers, often relying on manual tools or commercially available walking tractors, are demonstrably inefficient on steep slopes. This study presents the design, development, and performance evaluation of a novel single-axle power tiller equipped with a 60-cm- diameter cage wheel system. Solid Works 2017 software facilitated the design process, ensuring optimal functionality and structural integrity through finite element modeling. The final prototype incorporates user-friendly, portable, and farm-field-assembily parts production specifically tailored to address the challenges of variable hillside terrain. Field testing under controlled conditions assessed the tiller's performance metrics, focusing on tractive efficiency (TE) and net traction ratio (NTR). The evaluation employed a standardized load of 121.51 kg with in 175 cc Yamaha engine on sloped farmland with stony soil conditions, simulating a forward speed of 2 m/s. Systematic adjustments were made to pull force throughout the testing process. A positive correlation emerged between NTR and decreasing wheel slip, with the addition of a slanted cage featuring a 30mm angle iron groove demonstrating a further enhancement in this effect. Notably, the configuration utilizing a cage wheel achieved a significant increase in TE of 80.15% at minimal wheel slip of 9%. This research introduces a novel, cost-effective single-axle power tiller design, specifically addressing the tillage limitations encountered by hillside farmers. Prioritizing affordability, ease of use, and suitability for resource-constrained settings, this innovation has the potential to empower marginalized communities by replacing arduous manual labor with a more efficient and productive agricultural technology. The wider adoption of this design has the potential to create a paradigm shift in agricultural practices for these regions, leading to both economic and social advancements.

Keywords: - Hillsidefarm, Steep Slops, Pull, Solid works, SlantedCageWheel, TE, NTR

1. Introduction

In agriculture, farm power is a necessary input for prompt field operations that boost land productivity. Animal and human power are the main sources of power for agricultural operations in the majority of emerging sub-Saharan nations, including Ethiopia (Deribe, Getnet et al. 2021). The use of oxen is crucial in supplying the farm power needed for tillage operations (Tesfaye, Getnet et al. 2021). Using a Marsha plow, a traditional tillage technique calls for two perpendicular tillage operations in a flat farm field spaced apart by repeated plowing (Kebede, Temesgen et al. 2023). This uses a lot of energy from both animals and humans; it takes longer to prepare the seedbed. When traditional oxen drives provide shallow tillage and a long preparation period, farmers who depend on them for soil preparation cannot plow enough soil depth(Bagnall 2014).

Crop productivity decreases with delayed planting due to a lack of tillage time for seedbed preparation and the crop's growing season (Takele, Selassie et al. 2018). To address these issues with the conventional plowing system, finding a suitable plowing technique is essential to enhancing agricultural operations (Mengistu, Chala et al. 2019). Therefore, the small farm-home economy would profit from the introduction of appropriate mechanized technology, such as walking tractors (Workineh 2021, Yenewa and Molla 2022). A power tiller is designed mainly for the tilling of seedbeds in small farms and in hill farming for carrying out spraying operations on food crops (Díaz Lankenau 2020).

As many studies have shown (Holden, Wolfe et al., 2021) the use of tractors on farms for tillage purposes has a significant contribution to farm productivity (Challa, 2016). The findings of the study done in India revealed that the production of a farm with a tractor is more productive than that of an animal power farm (Mehta, Chandel et al. 2019). The growing shortage of agricultural labor and rising wage rates are not the only reasons for the accelerated mechanization of farm operations (Wang, Yamauchi et al. 2016). But factors such as time savings, efficient input application, transportation of farm inputs and production, and reducing drudgery also stimulate demand for farm machines (Diao, Silver et al. 2016).

According to a study by Gurusamy and Devaradjane (2015) in India, the development and mass production of multi-utility mechanized devices to suit the requirements of farmers are important for the growth of mechanization(Gurusamy and Devaradjane 2015). A walking tractor, also known as a hand tractor, has its control for field operations performed by walking behind it (Workineh 2021). It can replace animal power more effectively and help increase demand for human labor. The small and marginal farmers are the major users of custom-hired power tillers(Aryal, Thapa et al. 2021). Power tillers are preferred by small landholding farmers for all farm operations like puddling and preparatory tillage (Takeshima and Justice 2020). With an emphasis on increasing agricultural productivity, the Ethiopian government has made agricultural-led industrialization the cornerstone of its economic agenda (Kebede and Getnet 2016).

Apart from improved crop yield, the increased usage of farm power for cultivation creates further demand for related agricultural machinery that is well suited to small-scale Ethiopian farmers. But large commercial and medium farms only represent about 10% of the estimated 14.7 million farmers in the country(Berhane, Dereje et al. 2017). To support farm productivity and lower work intensity, most farmers in the nation have options besides the maresha plow and hand tools (Getachew Cherkos 2022). In Ethiopia's mountainous areas where farms are tiny and scattered, small tractors with just two wheels are a better fit than larger, four-wheeled ones. This is because small tractors can navigate tight spaces (Koroso 2016). They are also very versatile and can be used for seeding many more uses (Fuad and Flora 2019).

1.1 Background of the study

Farm machinery is crucial in agricultural production(Sharma, Jain et al. 2020), the ongoing development and adoption of farm machinery aim to optimize the efficiency of critical tasks(Van Loon, Woltering et al. 2020) such as land cultivation, harvesting, and associated processes. According to (Rakhra, Deb et al. 2022) mechanized agriculture involves the use of any mechanical tool in farming, including hand tools, animals, and mechanically powered technology. Traditional farming accounts for around two-thirds of the world's impoverished(Phiri, Malec et al., 2020), and increasing food demand and dietary changes necessitates agricultural intensification(Montt and Luu 2020).

According to (Berhane *et al*., 2017) study strategies to achieve agricultural expansion include increasing labor productivity through mechanization and intensifying land use with technology(Montt and Luu 2020). However, food security remains a challenge. In Ethiopia, small farm households face challenges in tillage operations due to intensive human labor, low input, and low productivity. According to Gebremedhin (*et al*., 2010) and others study shown tractor-powered farms are more productive than animal traction farms, and the average percentage of return on investment in mechanized farm machinery is twofold higher than non-mechanized farms(Sims and Kienzle 2016). Agricultural machinery capacity is a crucial parameter for evaluating and optimizing farm equipment selection and deployment strategies.

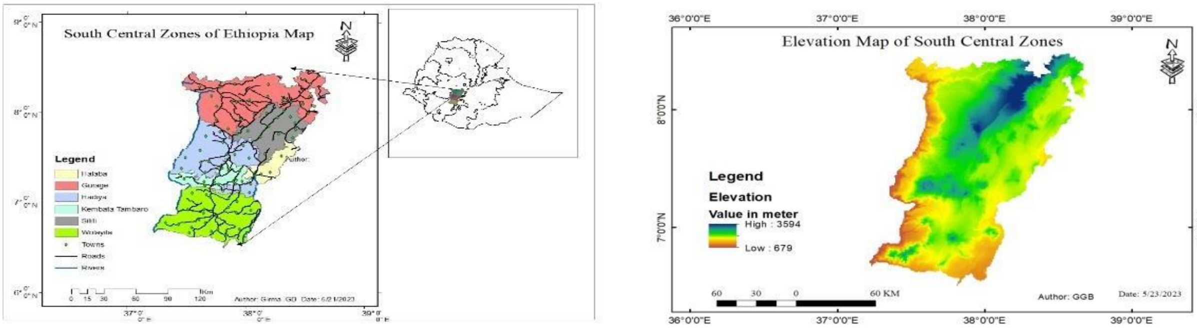
In the study area, agricultural machinery utilization was very low. The acute labor shortage was felt during the peak period of farm operations. Among all the farm operations, a notable level of mechanization was less than 5% (Ayele, 2022). Therefore, traditional tillage practices have long-standing and unsustainable effects on small farms' food security in the highlands of southern Ethiopia. In an effort to boost agricultural production, researchers are investigating how to maximize present marginal land use and apply low-cost mechanical tillage techniques. The primary goal of the research was to develop and manufacture single-axle power tillers suitable for the small and marginal farms in the region. And also, this endeavor is to overcome the high expense of the current tractor in the market as well as the drawbacks of labor-intensive, traditional procedures. Finally, it reduced the cost of tillage for low-income farmers and lessened their stress by providing them with a more effective substitute for traditional practices with an easily operable machine.

2. Materials and Research Methodology

2.1 Description of the Study Area

The geographic location of the study area is found in the central zones of southern Ethiopia. The location of administrative bounders lies roughly 140 km south of Addis Ababa and 180 km West of Hawassa on the Jinka- Jimma road, between 6° N and 9° N latitudes and 37° 0'' E and 39° 0’’ E longitudes. The study area is found in the central zones of south Ethiopia, particularly the former south nation nationality people’s regional state of Ethiopia Central zones. This study area includes, Halaba, Hadiya, woliyta, Kembata, Silte’ and Gurage zone. The research area's lowest points are found in Omo Valley (679 meters) and on the peak Anbericho in Kambata Zone (3594) meters above sea level.

In the conventional Ethiopian agro-ecological zonation and information obtained, the climate is characterized as temperate, or locally called arid (Kolla), sub-humid (woina dega), and high land (dega) weather conditions to permit the cultivation of a wide variety of crops, fruits, and food plants. Study area, elevation map soil categories were shown below in Fig: 1 (a, b, c)



(a) (b)

Figure 1 : Map, and Elevation of study area

Agricultural practices in the study area are significantly constrained by the region's steep, hilly topography. Coupled with this is the challenge of fragmented landholdings characterized by rocky terrain. Traditional farming tools and implements, often inadequate for the demanding conditions, are prevalent throughout the highlands. The design and functionality of these tools are positively influenced by the specific topographical and soil characteristics of the region.

2.2 Technical characteristics, Design development and model simulation of power tiller

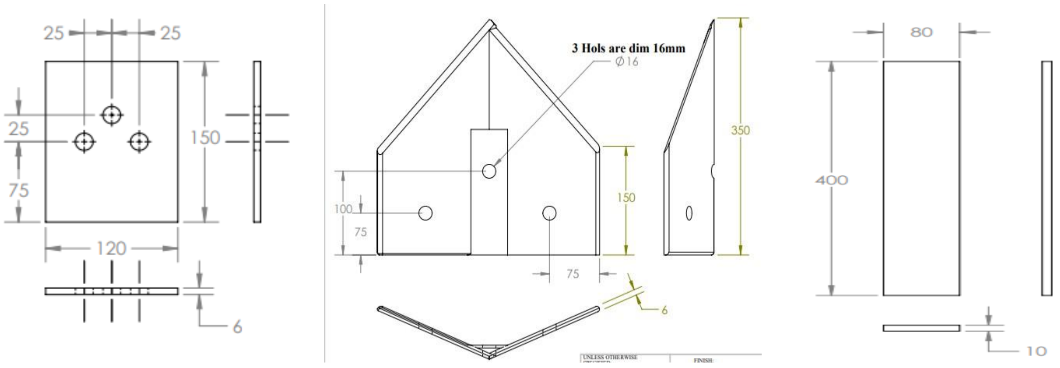
The tiller's design effectively addresses the challenges posed by steep, hilly terrain and fragmented landholdings common in marginal farming environments. Its modular structure facilitates on-site assembly and adaptability to diverse field conditions. Equipped with a 60cm-wide moldboard capable of single-pass plowing, the tiller significantly enhances efficiency, enabling farmers to cultivate up to 1.5 hectares daily. This innovative equipment offers a practical and efficient solution for small-scale farmers, surpassing the limitations of traditional tillage methods.

Focusing on technical aspects:

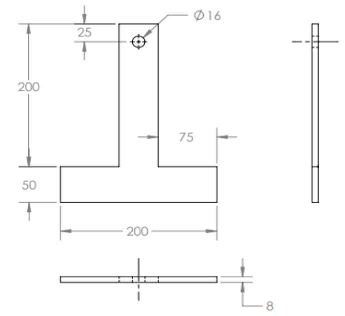
The tiller is specifically designed to address the challenges posed by steep, inaccessible terrains typically encountered in marginal farming environments. Its modular construction facilitates on- site assembly and adaptability to diverse field conditions.

This equipment is intended to overcome the limitations of conventional tractors, which are often impractical for small-scale farmers due to their size and cost. The tiller's high-efficiency moldboard, capable of a 15-25 cm cutting depth, is equipped with three 20 cm bottoms for optimal performance. With a total width of 60 cm, it enables efficient single-pass plowing. The machine's design encompasses a moldboard, power transmission system, and slanted cage wheel assembly, as shown in detailed in Figure 2(A-K) , Figure 3(A-F), and Figure 4 (A-J) are shown below.

Mouldboard Details



A B C



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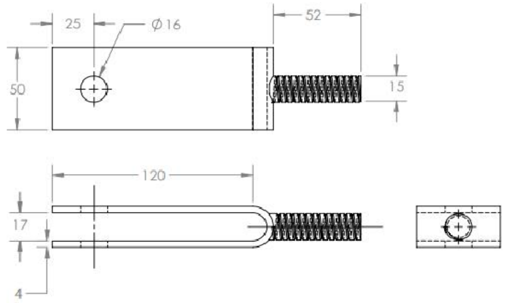

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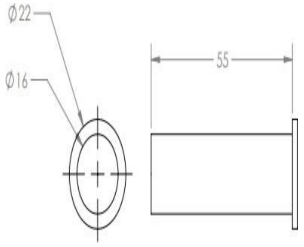

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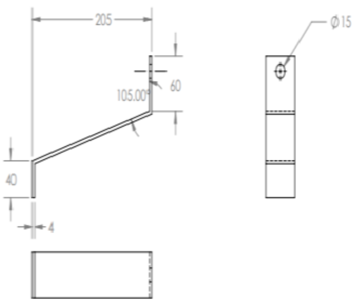

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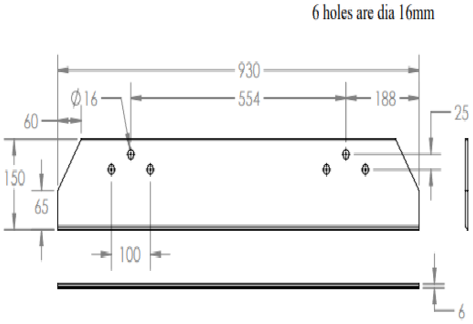

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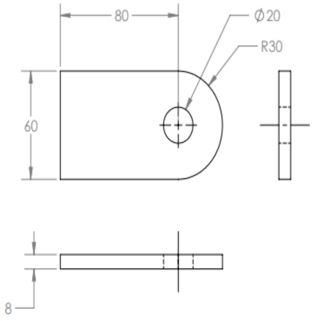

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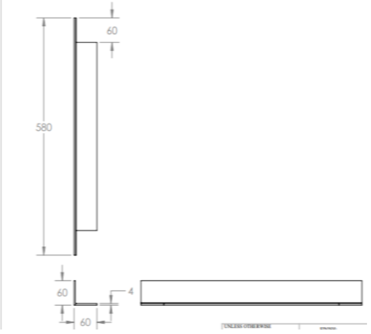

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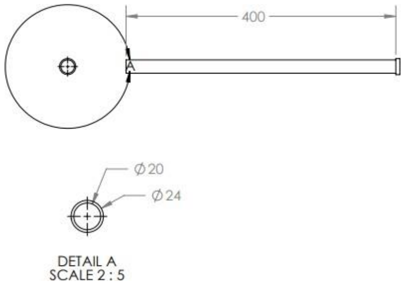
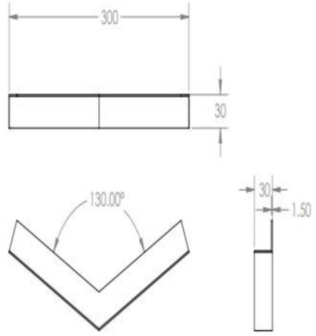


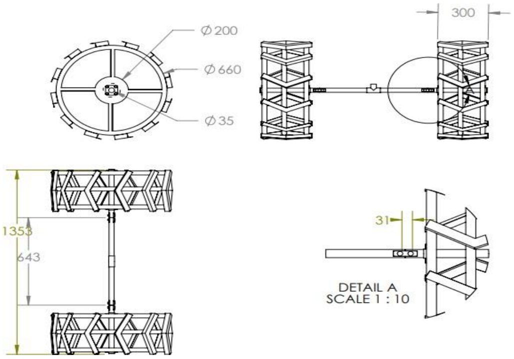
K

Figure 2: Mouldboard detail drawing

Cage detail with in shaft



A



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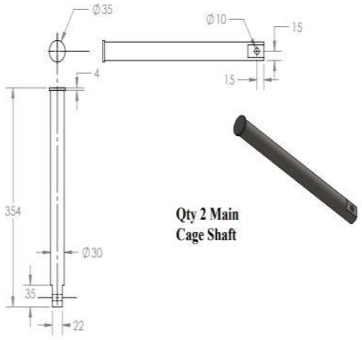

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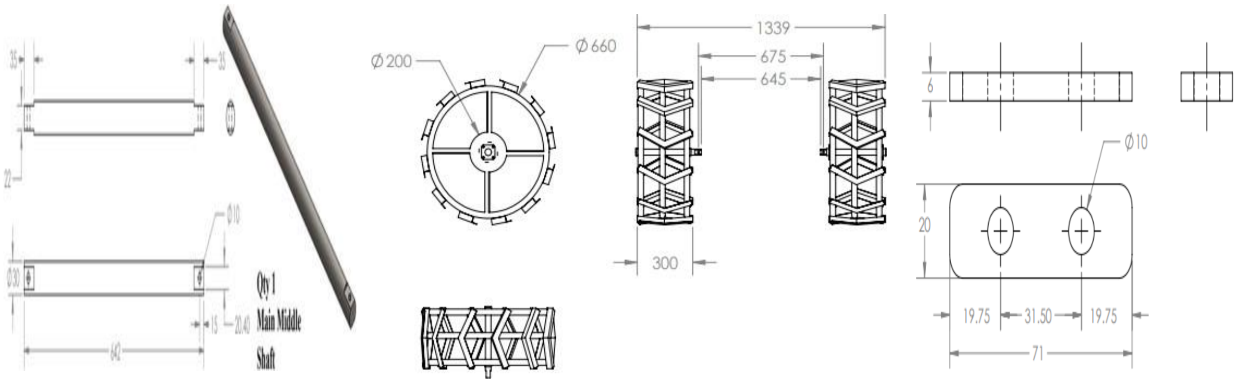
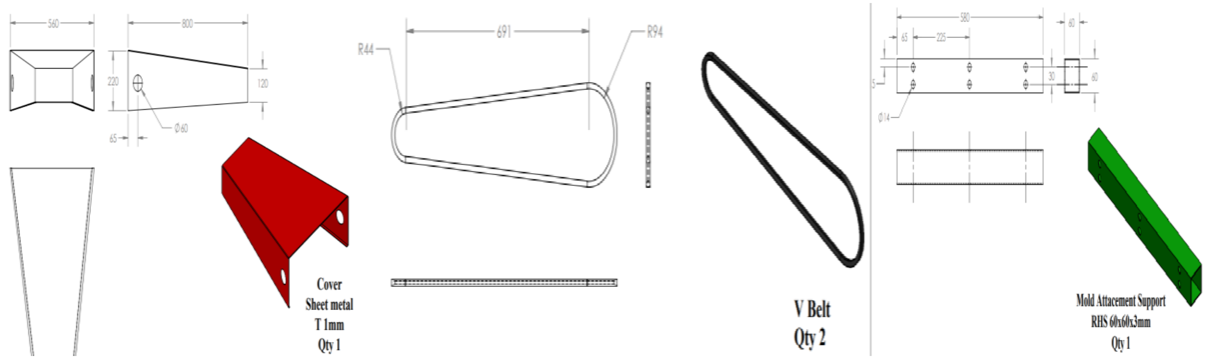


D E F

Figure 3: Parts of cage wheel details with shafts

Power Transmission System



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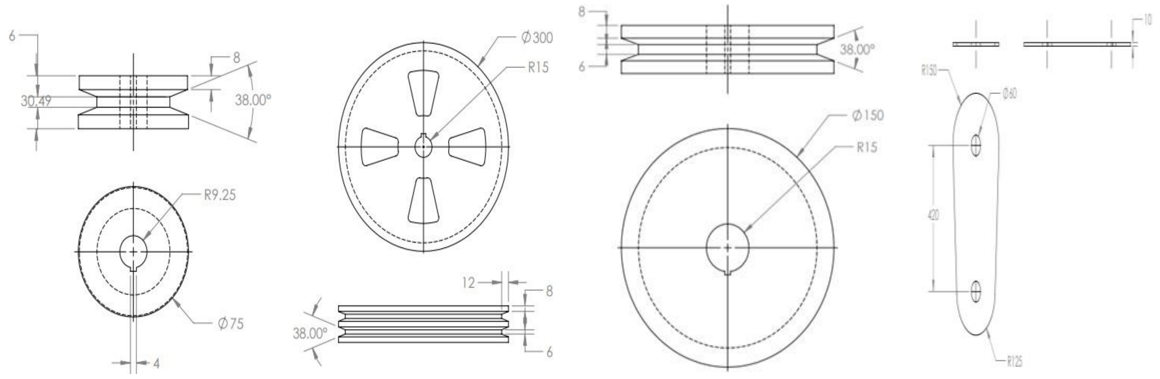

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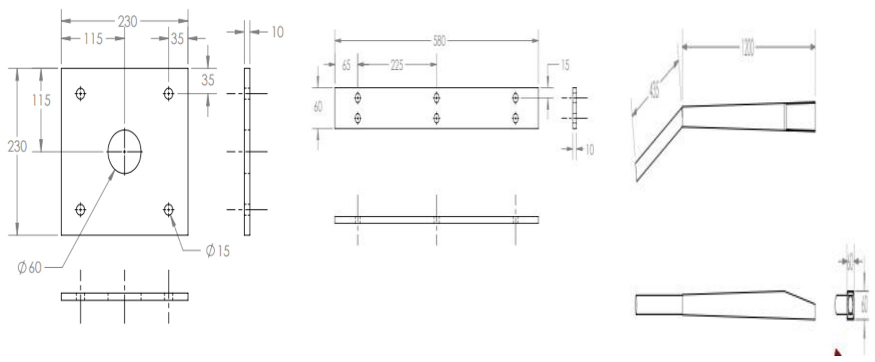


H I J

Figure 4: parts of power transmission system

3.3 Work methodology

Fig. 5 shows the methodology flowchart for overall work procedures. Initially, an existing walking tractor was studied to identify the parts to be redesigned, and a conceptual design was generated. Conceptual design incorporates all details. Selecting Engine Power for Small Tractors (Power Tillers): **A** multi-factorial approach considering diverse variables**.** such as farm field size; smaller fields (up to 2 hectares): Engines in the 5-8 horsepower range are generally suitable for light-duty tasks like tilling, weeding, and planting. Medium-sized fields (2–5 hectares): Engines ranging from 8–12 horsepower can handle heavier tilling, plowing, and light transportation tasks(Soleimani, Abbaspour-Fard et al. 2023).

Soil Conditions: Lighter, Sandy Soils: We required less engine power compared to heavier clay soils in our design consideration, which demanded more power for effective tilling and plowing. The engine power in our design was 11.66 hp of a Yamaha engin model 175 cc, which was selected depending on their working capacity and farm field size(McWilliams 1941). The main working flow chart started with material selection based on maximum firm soil condition considerations based on ASABSE 2018. Depending on the working drawings Shawn above Figures 2–4 to manufacture according to the flow chart diagram below

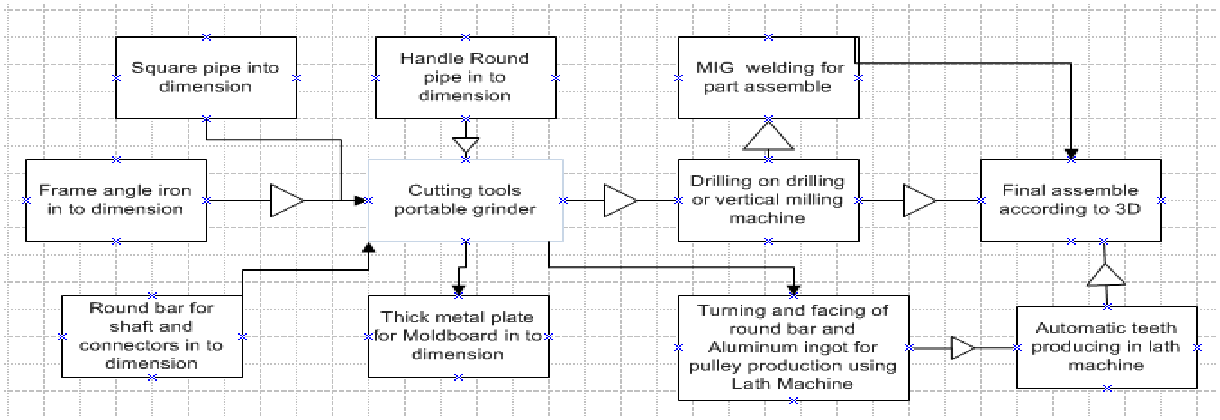


Figure 5: Flow Chart of Single Axle Power Tiller Production (source: my own design)

In our manufacturing workshop, the following machines, hand tools, and manpower were used to manufacture and test the product:.
Table 1: operational flow procedure in accordance with number order

Materials Categories 1	Work order 2	Machine type 3	Selected machine and cutting tools 4	Machine categories 5	Operation type 6	Tools to be Used 7	Parts to be done 8
Mild steel angle iron	Cutting in to dimension	Dwelt cutter	Milling with Ø16 end mill	Vertical milling	drilling	End mill	Mouldboard carriers
Mild steel round bar	Cutting to dimension	Dwelt cutter		Lath machine	Facing and turning	Centering bit, turning and facing tools	Main shaft and mouldboard connecting pin
Mild steel plate	Cutting to dimension	Portable grinding machine	Cutting disc Ø30	Lath machine	Drilling and Turning	Boring tools	Cage supporting disc
Mild steel round bar	Cutting to dimension	Dwelt cutter	Bench type cutter	Rolling machine	To roll	Rolling dais	Cage wheel
Mild steel plate	Cutting to dimension	Portable grinding machine	Cutting disc Ø30	Vertical milling	drilling	End mill	Mouldboard

Table 1: operational flow procedure (source my own design)

3.4 Analytical Method

To find the overall weight of the machine, we used the metal weight calculator, and the total weight of the machine is 121.51kg. The power required to drive the power tiller determines the draft force, but the draft force (D, KN) varies depending on the soil condition. Our design focuses mainly on firm soil. The drawbar serves as the primary interface for a tractor to transmit pulling force to implements. It acts as a crucial connection point**,** enabling the tractor to exert its traction capabilities and power various agricultural tools (Oberti and Schulze Lammers 2020).

$$\mathrm{DF} = \frac{r\, m\, g}{1000} \quad \ldots\ldots (1)$$ (Holden, Wolfe et al. 2021)

Where:

m = mass of pulled equipment and its load (kg)

g = gravitational acceleration constant 9.81 m/s

r = Resistance to travel is an additional draft force that must be included in computing power requirements. Values of resistance to travel depend on transport wheel dimensions, cage pressure, soil type, and soil moisture (He, Sandu et al. 2020). The value of r can be estimated using (ASABE Standards, 2015a) as shown in Table 2 as below:

DF = $\frac{1.842 * 121.51kg * 9.81m/s2}{1000}$ = 2.196KN, Our design, considering it most probably works on three furrows of firm soil draft force, requires 2.196 KN for tilled soil, 1.92 KN for tilled soil, and 2.23 KN for soft soil. To find resistance travel ratio, r

$r = \frac{1}{Bn} + 0.04 + \frac{0.5sl}{\sqrt{Bn}}$ ………………………………...(2) (Condotta, Brown-Brandl et al. 2018, Shafaei, Loghavi et al. 2018)

Table 2: Values of soil index factor B_n, slippage *Sl*, and draft coefficient X_d for various surfaces on which equipment is towed (ASABE Standards, 2015a) for 2-wheel drive tractors (He, Shenvi et al. 2019).

Surface Condition	soil index factor *Bn*	slippage *sl*,	Equivalent coefficient of friction (μ)
Firm soil	0.72	0.08-0.1	0.43–0.53
Tilled soil	0.67	0.11-0.13	0.40–0.46
Soft soil	0.55	0.14-0.16	0.26–0.31
The listed values are for 2-wheel drive tractors			

$r = \frac{1}{Bn} + 0.04 + \frac{0.5sl}{\sqrt{Bn}}$

Where: B_n = soil index factor Table: 2 design considering maximum soil strength surface condition of firm soil. Sl = decimal value representing tractor wheel slippage

For design of firm soil: r, ratio, resistance to travel

$r = \frac{1}{0.72} + 0.04 + \frac{0.5*0.09}{\sqrt{0.72}}$ = 1.842, for tilled soil r is 1.603 and soft soil r is 1.87

Given the speed and draft force (KN), draft power is calculated by:

PD = FiVi/3.6 .... from equation (1)

Where

PD: the tractor draft (pull) power (kW), *Vi* = the average forward speed of the pulling (km/h), come from pulley liner speed of belt to drive wheel of 1.9635m/s~2m/s

$Pd = \frac{2.196KN*7.2}{3.6}$ = 4.392 KW therefore the power required to draw the force is 4.392 KW its conversion requires to 5.88 hp and its above for a minimum power for firm soil for primary tillage operation within three tine.

The friction force (F_f) between a wheel and its surface can be expressed as $F_f = R\mu$, where R represents the reaction force (normal force) acting on the wheel and μ is the equivalent friction coefficient (accounting for material and surface factors). Refer to Table 2 for typical values of μ. Since R is equal to the dynamic load (W) acting on the wheel axle, and the net tractive force (Ft) is equal to the friction force, we can derive the formula $Ft = W\mu$, directly relating the tractive force to the applied load and the coefficient of friction.

The selection of suitable tractor engine power for implement operation necessitates the estimation of drawbar power requirements. The American Society of Agricultural and Biological Engineers (ASABE) provides valuable data and methodologies within their 2015 standards to facilitate the calculation of a tractor's gross flywheel power necessary to effectively pull specific implements.

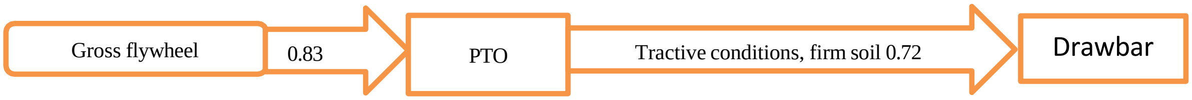


Figure 6: power transmission diagram of the walking tractor

These values were estimated based on data presented by (Kolator and Białobrzewski 2011, Mathew, Sharipov et al. 2023).

$Ff = \mu W$... (3)

Ff = $0.48*9.8m/s^2*121.51kg$ =571.583N, in our design consideration is maximum firm soil ability to resistance pull in one journey it losses 571.583N. Where: μ = coefficient of friction. μ for firm soil is 0.48 from table 2. The theoretical velocity (v) is determined by the wheel's rotational velocity (ω) times the rolling radius (r) as shown in Equation 4, but the actual wheel velocity (v) is less due to the relative motion at the interface between the wheel and the surface. The phenomenon where a wheel's actual speed is less than its theoretical speed due to factors like resistance is quantified by the travel reduction ratio, also known as slip. This ratio expresses the proportion of lost speed relative to the ideal speed and can be estimated using Equation 5 shown how the travel reduction ratio can be estimated:

$Vt = \omega r$ ………………………………………………………………………………… (4)

For design considered of 4.39 kW/3000 RPM petrol engine of 2WD tractor of firm soil condition theoretical velocity (v) = $\frac{2600rev}{60x4}x0.72 = 2600rev/4 * min * 0.72$ =7.8rev/s, and r is 0.330m. According to ASABE Standards (2015) the power at the tractor PTO is about equal to the engine gross flywheel power multiplied by 0.83. Expected minimum engine speed output 1440 rpm and transmission ration of pulley built with in V-belt is 4:1 therefore rear wheel speed 1440/4 rpm = 360rpm and rolling radius is 330mm, theoretical speed of tractor is Vt = 2prx360/60m/s = 12.43m/s. when r is 300mm Vt is 11.31m/s. But according to ASABE Standards (2015) for firm soil slippage is 0.09 and actual velocity (V_a).

$Va = Vt\,(1 - Sl),$……………………………………………………………………………(5)

Where:

Vt = theoretical velocity of the wheel (m/s), r = wheel rolling radius (m/s), and

Sl = travel reduction ratio, or slip (dimensionless)

Va = Vt (1- *Sl*), = 11.3m/s (1-0.09) = 11.31m/s (4:1)

The models used to calculate the tractive force generally use the travel reduction ratio as one of the variables. Considering the existence of the motion resistance force, in the contact between the wheel and the surface, it is necessary to generate a friction force greater than the motion resistance force at the wheel-surface contact to produce a tractive force.

ω = angular velocity of the wheel

NTF = net tractive force

r = rolling radius

F_f = motion resistance force

W = dynamic wheel load

GTF = gross tractive force

R = vertical reaction force of the wheel

TW = torque transferred to the wheel

V_a = actual velocity of the wheel

G = soil reaction at resistance center

Imagine the wheel and surface pushing against each other as they roll. This creates a "motion resistance force" (Ff) that needs to be overcome for the wheel to move. To achieve this, we need a stronger "gross tractive force" (GTF) generated by friction between the wheel and surface. GTF represents the maximum force available for pulling the wheel forward if there were no energy loss due to deformation. When analyzing wheel traction, the "motion resistance force" (Ff) plays a key role. This force arises from the deformation of the wheel and surface during rolling, requiring energy to overcome. To achieve forward motion, the friction between the wheel and surface needs to generate a "gross tractive force" (GTF) larger than Ff. Essentially, GTF represents the force available for pulling the wheel if there were no energy loss from deformation. Since 25^0 is mouldboard contact angle during the traction it shown figure 8.

$$\mathrm{NTF} = \mathrm{GTF} - \mathrm{Ff}$$

$$\mathrm{NTF} = \mathrm{RSin}25^0 + \mu\mathrm{Rcos}25^0 - \mu\mathrm{Wcos}25^0$$

$$TF = RSin25^0 + \mu Rcos25^0 - \mu Wcos25^0$$

Traction theories application in the firm soil

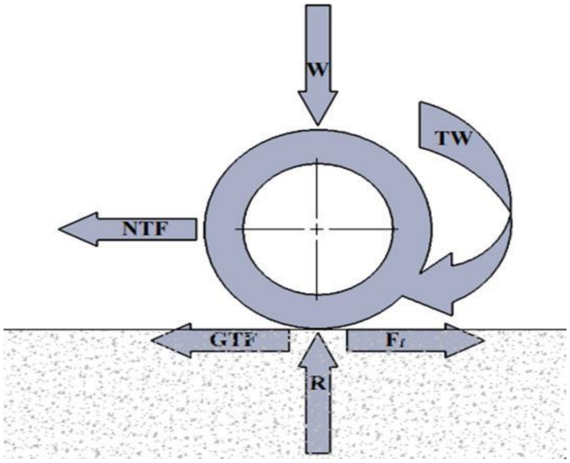


Figure: 7 dynamics of traction

$$\text{Traction efficiency} = \frac{\text{Net tractive force (N)x actual velocity of the wheel (m/ s)}}{\text{Torque transferred to the wheel axle (N m) X angular velocity of the wheel (rad/ s)}}$$

$$TE = \frac{770.9x11.31 N.m/s}{110.68Kgx9.81x0.3\ N.m\ x6x3.14x2/s}$$ =7940.3/12273.5 =64.7% When the wheel diameter is 0.6m

$$TE = \frac{846.33x13.4\ N.m/s}{121.51Kgx9.81x0.315\ N.m\ x6x3.14x2rad/s} x100\% = 11340.8/14148.87 = 80.15\%.$$

With the addition of a slanted wheel groove to minimize wheel slippage on increasing the radius from 0.300m to 0.315 m, traction efficiency increased from 64.7% to 80.15%.

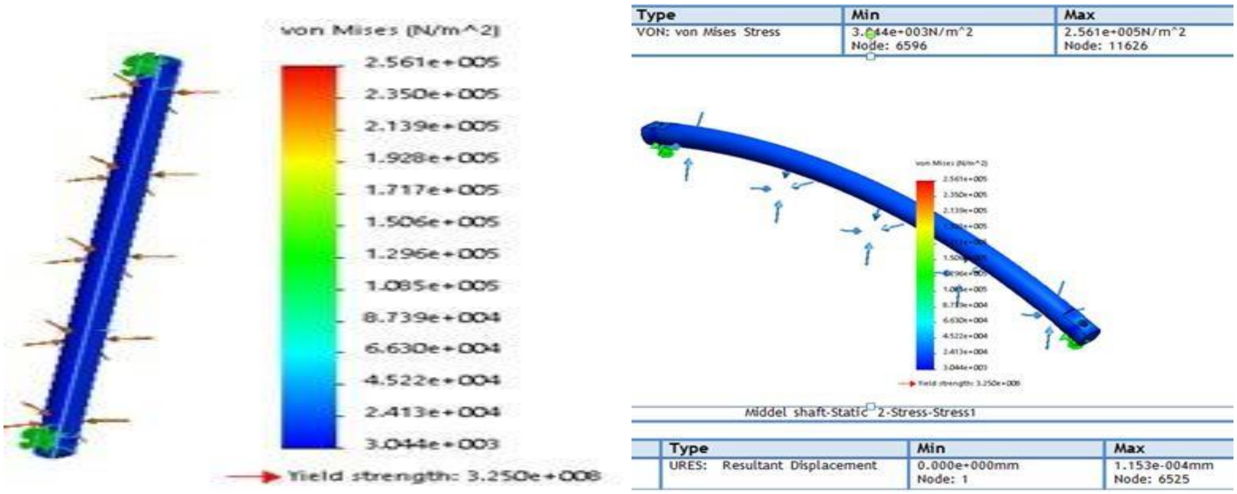
4.0 Results and discussion

The model and simulation results are discussed as shown below.

4.1 Results

A comprehensive structural analysis was performed on critical components of the new power tiller design, including the main shafts, moldboard connectors, and tip, using SOLIDWORKS2017 software. Based on the initial design concept and subsequent simulations, these analyses assessed component strength and potential failure points under various operating conditions encountered in hilly terrain. The simulations determined that a minimum engine power of 4.39 kW is required for optimal performance. The following figures graphically depict the results of these analyses, including detailed models of the main load shaft and its potential failure modes

Figure: 9 . The main load carrier and power transmission shaft



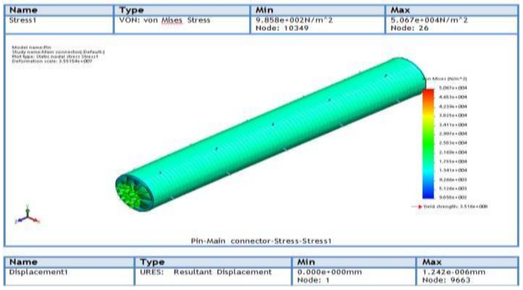
Type	Min	Max
VON: von Mises Stress	3.044e+003N/m^2 Node: 6596	2.561e+005N/m^2 Node: 11626

Type	Min	Max
URES: Resultant Displacement	0.000e+000mm Node: 1	1.153e-004mm Node: 6525

Figure: 8 stress and strain analysis result on main shaft

Yield strength of the shaft is 325MP, but maximum applied load on main shaft is 1.2151KN and minimum yield pressure on 3.044KP and ultimate yield pressure 0.2561MP. The deformations of the shaft run from minimum 0.000e+000mm and maximum 1.153e-004mm .Therefore, the machine works on a given applied load without failure. The graphical representations of main shaft analysis of stress, and strain were shown as below.

Model failure analysis of the moldboard carrier connector

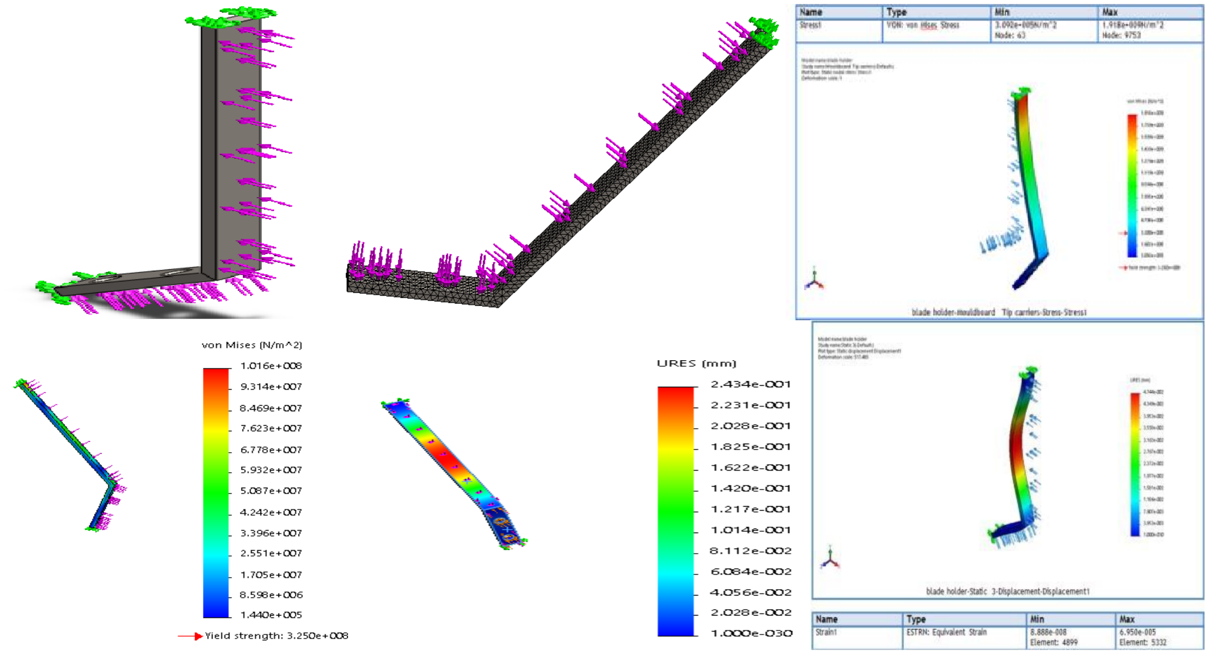


Name	Type	Min	Max
Stress1	VON: von Mises Stress	9.858e+002N/m^2 Node: 10349	5.067e+004N/m^2 Node: 26

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+000mm Node: 1	1.242e-006mm Node: 9663

Figure: 9 stress and strain analysis result on main moldboard connector

Yield strength of the shaft is 325MP, but maximum external applied load on main connector shaft is 1KN and minimum yield pressure on 0.9858KP and ultimate yield strength 50.67KP. Maximum deformation of the connector of moldboard is 1.242e-^{006}mm. Therefore, the machine works on a given applied load without failure. Modeling of failures analysis of moldboard holder with in tip applying varies human applied pressing load with different operating force.



Name	Type	Min	Max
Stress1	VON: von Mises Stress	3.092e+005N/m^2 Node: 63	1.918e+009N/m^2 Node: 9753

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	8.888e-008 Element: 4899	6.950e-005 Element: 5332

Figure: 10 stress and strain analysis result on moldboard holder with in different applied load.

Minimum pressure 0.3092MPa and Maximum pressure 1918MPa and maximum external applied load on adult man average handle are 150N, so the yield strength is 325MPa. Therefore, the machine works properly on a maximum load without failure. For ductile materials like steel, factor of safety equivalent to yield strength to Working stress. And in our design factor of safety is 3.

4.2 Discussions

Stress strain analysis results of main shaft given the clues of failures on maximum applied load. Therefore, Yield strength of the shaft is 325MP, but maximum applied load on main shaft is 1.251KN and minimum yield pressure on 3.044KP and Maximum limit of the shaft is 0.2561MP . And maximum Elastic deformation of the shaft is 1.153e-004 mm and Min 0.000e+000 mm**.** Therefore, the machine works on a given applied load without failure. Elastic deformation Occurs in our design when the material deforms under stress but returns to its original shape when the stress is removed. In other words, the material can withstand a certain amount of strain without undergoing permanent deformation. The graphical representations of connecting main shaft analysis of stress, and strain were shown below

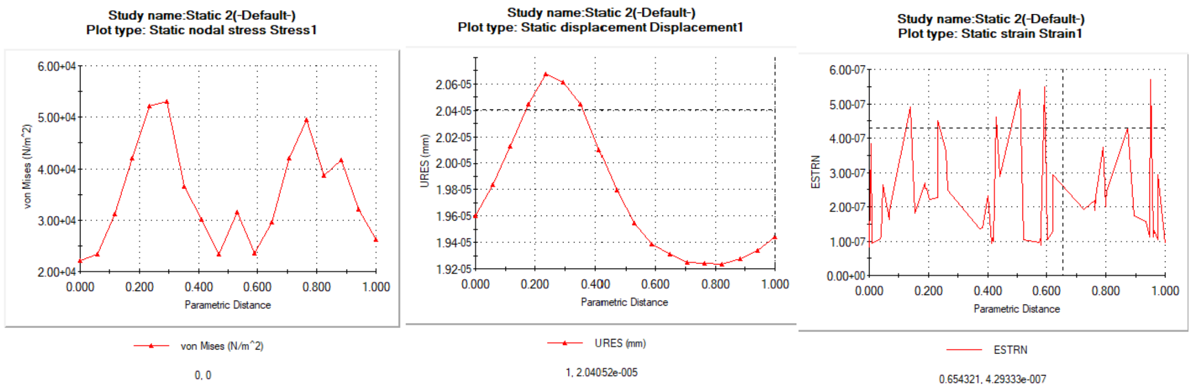


Figure 11: Modeling failures analysis of main shaft graphical representations

Similarly : Modeling failures analysis of moldboard connector minimum pressure 0.3092MPa and maximum pressure 1918MPa and average maximum applied external force of adult man on field varies from load on handle are 100N to 150 N, so the stress strain of moldboard holder with in tips inside pull of draft force and the external pressing operational force producing maximum and minimum stress 1.440e+005P and 1.016e+008P and deformation elongation are shown respectively 0.000e+000mm, and 2.434e-001mm. Yield strength is 325MPa. Therefore, the machine works properly under the maximum applied load without failure. For ductile materials like mild steel, the factor of safety in our design was 3.

To come to moldboard carrier connector with in main power transmitting part: Yield strength of the connecting pin is 325MP, but maximum external applied load on main connector pin is 1KN and minimum yield pressure on 0.9858KP and ultimate yield strength 50.67KP. Maximum deformation of the connector of moldboard is 1.242e-^{006}mm. Therefore, the machine works on a given applied load without failure.

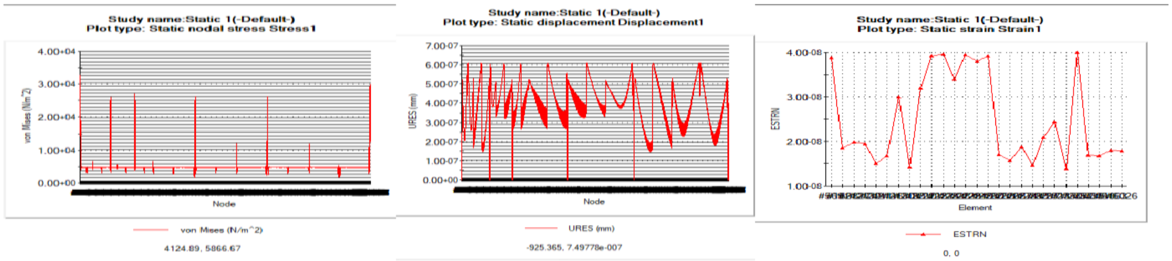


Figure 12: Failure analysis with graphical representations of moldboard connectors

To come to moldboard in figure 14 shown below : the graphical representations of moldboard with ultimate stress are in allowable stress strain graphs. The yield strength of the shaft is 325 MP, but the average external applied load of the adult man's varies from the main pressing handle 100 N to 150 N, with a minimum yield pressure of 63.56 P and an ultimate yield strength of 3.161KP. The maximum elastic deformation of the main shaft was 2.444 e-007 mm. Therefore, the machine works properly under a maximum load without failure. For ductile materials like mild steel, the factor of safety is equivalent to yield strength by working stress, and in our design, the factor of safety is 3.

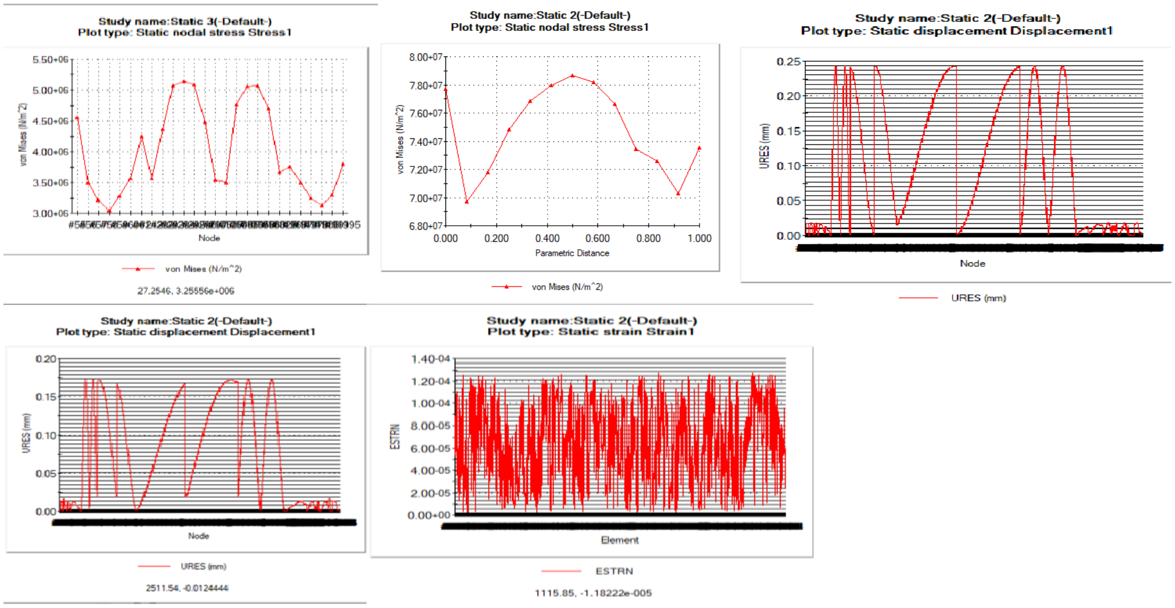


Figure 13: Failure analysis with graphical representations of moldboard

5. Conclusions

From this study following conclusion were made:

Single-Slanted wheel power tiller transforms marginal and small households South Ethiopian Agriculture

Challenge: Vast tracts of fertile land in South Ethiopia's Central Zones remain uncultivated due to their rugged terrain, inaccessible to conventional tractors. This poses a significant barrier to agricultural development and food security in these resource-constrained regions.

Innovation: The single-slanted wheel power tiller emerges as a game-changer, designed to unlock these previously uncultivated lands. Its unique design conquers challenging terrains, expanding arable area and fostering food security, improved livelihoods, and economic empowerment for smallholder farmers.

Beyond Technology: This innovation represents a paradigm shift. By empowering marginalized communities, it ignites a socio-economic renaissance. Increased agricultural productivity bolsters farm profitability and fosters sustainable practices, turning farmers into drivers of economic development.

Affordability as Key: Unlike its expensive counterparts, the tiller prioritizes affordability through a streamlined design and exceptional fuel efficiency. This democratizes access to mechanization for resource-constrained farmers, signifying a pathway to economic independence and dignity.

Enhanced Productivity and Sustainability: The tiller's agility and potent engine translate to rapid land preparation and efficient cultivation, leading to significant yield increases. This not only fills plates but also empowers farmers and fosters sustainable practices.

Impact beyond farms: The tiller's impact extends beyond individual farms, strengthening regional food security, injecting dynamism into local economies, and fostering self-reliance. This empowerment transcends the farm gate, contributing to improved healthcare, educational opportunities, and a brighter future for generations.

More than technology: This tiller embodies a transformative approach to agricultural accessibility. It overcomes long-standing limitations, unlocking vast swathes of land and paving the way for vibrant agricultural frontiers. This tangible impact empowers communities through enhanced food security, economic dynamism, and improved quality of life.

Technical Specifications:

Weight:	Dimensions:	Pulling Capacity:	Engine Power	Cost	Daily Coverage
122kg	3.32m x 1.4m x 1.35m	2.2kN	4.39kW	87,000 ET birr	1.5 hectares (operated for 8 hours)

Validation and Safety:

Rigorous testing using ASABE standards confirmed the machine's functionality and safe operation under ordinary working conditions, even on hillsides. Therefore, the single-slanted wheel power tiller holds immense potential to transform South Ethiopia's Central Zones agriculture. By unlocking vast tracts of land, empowering communities, and fostering sustainable development, it offers a brighter future for the region and its people.

AUTHORS CONTRIBUTION STATEMENT

Girma Getahun, Kishore Purushottam Kolhe, Mihrat Denanto, and Kessahun Gashu conceived and designed the machine; performed the experiments; analyzed and interpreted model simulation; contributed materials for prototype production; used analysis tools; and wrote the paper.

Data availability statement

Data included in article /supplementary materials/referenced in article

Funding statement

This study was undertaken independently of any specific grant funding from public, commercial, or non-profit organizations.

Declaration of competing interest

The authors affirm their adherence to ethical research standards and declare the absence of any known financial or personal conflicts of interest that might have impermissibly influenced the findings presented in this paper.

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