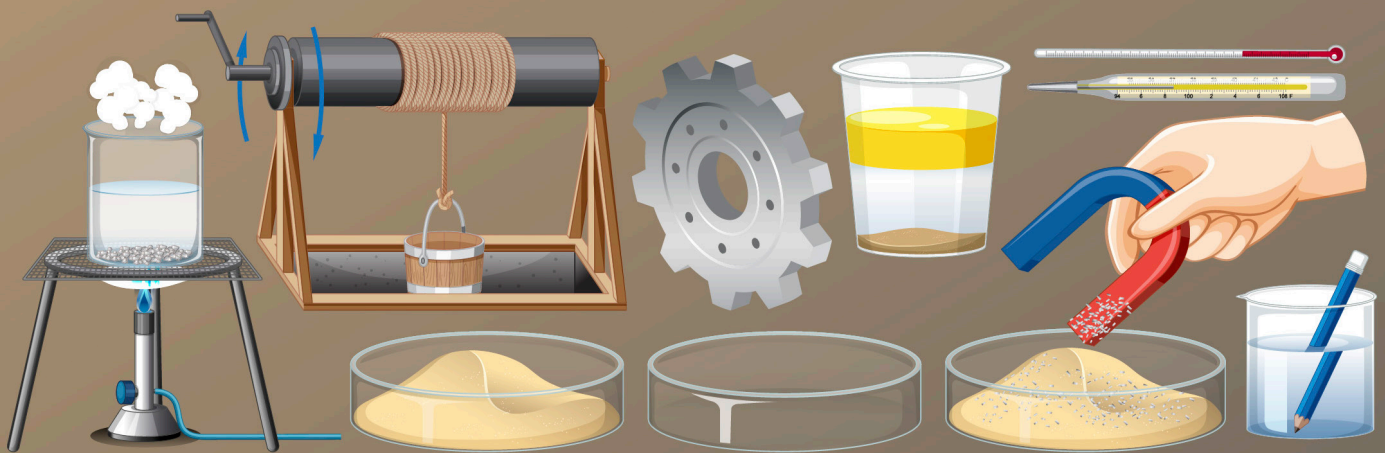




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Development of Tractor Drawn Combined Tillage Implement

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ABSTRACT

Soil tillage is one of the most vital and energy-intensive processes in agriculture, demanding significant time and resources. The cost as well as time of operation plays a critical role in choosing implement for tillage. Combined tillage involves using two or more different tillage tools simultaneously to prepare the soil, reducing the need for multiple field operations. This method was designed to save time, fuel, and energy while lowering operational costs. Additionally, it helps minimize soil compaction, labor expenses, and fuel usage by completing multiple tillage tasks in a single pass. Traditional tillage methods, on the other hand, are becoming more costly due to increased time, fuel, and equipment expenses. They also contribute to greater soil damage and compaction because of the repeated passes needed for seedbed preparation. Hence, the purpose of this study was to develop a tractor-drawn combined tillage implement. The developed implement comprised fine soil working tools with pulverizing roller by reducing the number of passes by combining two tillage implements. In a single run the combined tillage implement performs secondary tillage operations. The costs of operation of tractor-drawn combined tillage were 1707.43 Birr/hr whereas the break-even point, payback period, and benefit-cost ratio of the tractor-drawn combined tillage were 1,349.45 hr/yrs, 1.84 yrs, and 4.34, respectively.

INTRODUCTION

Tillage is the mechanical preparation of soil to create optimal conditions for crop growth. It involves breaking up compacted soil layers to a specific depth and loosening the soil structure, allowing roots to spread and develop more effectively (Zhou *et al.*, 2020). This process also includes managing plant residues to establish a suitable seedbed for planting, ultimately supporting grain production for human consumption. By disturbing the soil, tillage helps release nutrients, control weeds, and improve water infiltration and aeration (Reicosky & Allmaras, 2003). As a fundamental agricultural practice, tillage promotes healthy root development, reduces soil compaction, enhances air circulation, and suppresses weed growth (Al-Shamiry *et al.*, 2020). Nowadays, traditional tillage methods are costly, labor-intensive, and require multiple passes, leading to increased soil compaction. Additionally, conventional tillage is known for its low fuel efficiency. As Digman (2012) noted, merely 20% of a tractor's diesel fuel energy reaches the drawbar, with only 4% of that energy actually used to break up the soil. Given these inefficiencies, it is crucial to explore alternative approaches that optimize tillage operations. One effective solution is adopting combined tillage implements, which perform multiple functions in a single pass. This method is particularly beneficial for farmers who rely on conventional tillage, such as those in Ethiopia, as it helps reduce costs, save time, and minimize soil degradation.

According to Prem *et al.* (2016) defined combined tillage is the way in which two or more implements operate at

the same time in order to manipulate the soil. In a general sense, combined tillage means integrated management of resources such as time, energy, fuel, labor, soil, and water conservation, on the other hand, increasing yield and better utilization of natural resources. It also contributes to and sustains agriculture production. Tillage implements operate using two primary mechanisms: sliding motion and rotating motion. Implements such as moldboard plows and cultivators employ a sliding action to slice through the soil. In contrast, disc plows, disc harrows, clod crushers, and rollers utilize rotational movement to cut and break up the soil. Due to soil friction and the larger contact area, sliding-type tools require greater draft force compared to rotating-type implements. Interestingly, rotary implements can generate a negative draft, enhancing efficiency. According to the research done by Parmar and Gupta (2016) revealed that combined tillage implements significantly improve energy efficiency, reducing operational costs by nearly 50% and saving 50-55% in time compared to single-pass conventional tillage tools. In Ethiopia, most farmers still rely on conventional tillage methods that excessively disturb the soil structure. These traditional practices exacerbate soil compaction while making farmland more vulnerable to both wind and water erosion. The combined tillage equipment currently available in the country is primarily imported, making it prohibitively expensive for most farmers. Unfortunately, these imported solutions fail to address key local needs, they weren't consider for small-scale mechanization, lack affordable power requirements, and aren't suitable for highland farming conditions. The overall dimensions and

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weight of the tillage tool were heavy, not easily dismantled, or repaired and it was complicated. Nowadays there are combined tillage implements in the world that operate soil tilling purposes within a short period in a single pass but they are very expensive for our farmers in order to import them. So to alleviate this problem developing combined primary and secondary tillage implements for seedbed preparation is mandatory. Governmental and non-governmental organizations distribute a lot of tractors for the farmers, youths, and Biro of Agriculture in different ways. But most of them have been distributed with small amounts of tillage implements and accessories. Hence this was the best chance for this activity to be initiated. Therefore, this activity aimed to develop combined primarily and secondary tillage implements.

MATERIALS AND METHODS

Materials

Materials used for performing the prototype production of combined tillage implements were a mild steel square and rectangular pipe, different size bolts and nuts; different size angle iron, sheet metal, UCP bearing, flange bearing, MS rod, and MS flat were used.

Methods

Development Considerations

The components of combined tillage implement were developed and fabricated based on the parameters like functional requirements, engineering and general considerations at Asella Agricultural Engineering Research Center (AAERC).

Assumptions Considered

The following assumptions were made during the development of the combined tillage system with a pulverizing attachment for the cultivator: The tractor's average operating speed during field testing ranged from 3 to 7 km/hr, The maximum soil resistance was assumed to be 0.25 kg/cm² and a seven-tine cultivator with a 22 cm spacing between tines and a working depth of 15 cm was used.

General Considerations

The implement should meet the following criteria: It must be easy to develop, safe to operate, and require a power capacity suitable for tractors with more than 55 hp, it should slice soil uniformly and break it down into fine particles and the developed should be cost-effective while maintaining sufficient strength and durability.

Descriptions of the Implement

Combined tillage implement was developed to operate primary and secondary tillage operations in a single pass to ensure timeliness in seedbed preparation. The developed prototype consists of the following main components: mainframe, cultivator tines, and two rollers with pulverizing blades, three-point linkage system, and depth adjustment system. The overall dimension of the

developed combined tillage implement was 2150 mm in length, 1550 mm in width, and 1530 mm in height.

Mainframe

The frame is meant for holding different components of the developed combined tillage implement. It was subjected to bending, tension, and vibrations. The developed frame was light as possible to reduce the cost, soil compaction, and propelling power but yet strong enough to resist the shocks due to rough ground or obstacles. The frame, which supports a cultivator with pulverizing attachment units, must be rigid enough to withstand the weight of the whole assembly without buckling to prevent vibration or collapse of the implement. It was necessary to determine the load that the frame can withstand without crippling or buckling. The frame members were joined by welding at their ends to achieve a rigid fixed-type connection. The crippling and buckling load (P_{cr}) under different end conditions was determined using Euler's theory, as expressed in the following equation (Khurmi & Gupta, 2005).

$$P_{cr} = \frac{\pi^2 EI}{\left(\frac{Le}{r}\right)^2} \quad \dots(1)$$

Where, E = modulus of elasticity for the mild steel material (E= 210 GPa), A = cross-section area square pipe shape, cm², Le = effective length of the frame, cm, r = radius of gyration of the cross-section; and I = polar moment of the cross-section. Based on the above equation (1) mainframe was fabricated from the square pipe having a determined size of 80 × 80 × 2 mm for accommodating cultivator tines, three-point linkage systems, and two rollers with pulverizing blades. All components of the cultivator and roller were assembled and fitted on the frame.

Three -Point Hitch

Three point hitches was fabricated from Ms Flat iron. The overall dimension of the developed three point hitch was 2150 mm in length, 1550 mm in width, and 1530 in height.

Cultivator Tynes

The cultivator performs fine soil operations such as breaking clods and refining the soil to achieve an optimal seedbed at the required working depth. Additionally, it helps eliminate weeds that emerge after ploughing. The implement features two staggered rows of tynes mounted on its frame, ensuring sufficient clearance to prevent clogging by allowing clods and crop residues to pass through freely. Each tine was developed with a cutting unit welded to one end of the share, while the opposite end was bolted to the frame for depth adjustment. The tine's radius of curvature was determined using the equation provided by Sharma and Mukesh (2010).

$$R_c = (h_0 - l_1 \sin \alpha) / (\cos \alpha) \quad \dots(2)$$

Key Parameters and Calculations: l = Length of the tine's breast section (mm), α = angle formed between the tine

surface and ground (degrees), h_0 = vertical distance from the tine tip to the bent portion (mm). The tine's overall height (H) is determined by its mounting configuration on the frame. For proper ground clearance, the minimum distance (H_1) between the soil surface and frame's lower edge should exceed 200 mm. typical design parameters include: Tine slope range: 100-250 mm, Maximum curvature radius: $R \leq 120$ mm. Using standard cross-section dimensions ($b \times h$ in cm^2) and breast length (L), with reference values: $h_0 = 140$ mm, $l = 110$ mm, $\alpha = 25^\circ$. These parameter selections align with the research of Varshney *et al.* (2005). Substituting these values yielded a calculated curvature radius of 103.2 mm, which satisfies the development requirements.

$$H_T = a_{max} + H_1 + \Delta H \quad \dots(3)$$

Developed Parameters and Calculations: where, ΔH = Length of the tine's upper mounting section it was assumed as 100 mm and $H_1 = 633.5$ mm (reference measurement), a_{max} = calculated maximum deflection (46.50 mm). Substituting these values into equation (3)

yielded a total shank height (H) of 780 mm, measured from the tine tip to the frame connection point. During field operation, the effective draught force (D) acts at the tine tip, generating bending stress (σ) at the shank's bent portion due to soil resistance. For design purposes: The study area's sandy loam soil was classified as heavy soil, a unit draft of 0.25 kg/cm^2 was taken. The resulting draft force on the cutting blade was calculated using the specified equation:

$$D = k_0 \times n \times w \times d \times SF \quad \dots(4)$$

Where, D = draft force, N, K_0 = soil resistance, kg/cm^2 , w = Width of tine, cm; d = Depth of tine, cm; n = number of tine, SF = factor of safety. Therefore, total draught exerted on the cultivator tine was 4,708.8N and the determined each draft of the cultivator tines was 672.68 N. The shank of the cultivator was fabricated from a rectangular shape made up of MS material with 225 mm width, 600 mm length, 780 mm height, and 103.2 mm radius of curvature was fabricated and used for the study.



Figure 1: Diagram showing the developed cultivator

Pulverizing Roller

Pulverizing roller attachment to the rear back of the cultivator with spike blades pulverizes the soil to a greater degree. Tractor-drawn pulverizing roller attachment for the cultivator was mounted at the back of the cultivator. The pulverizing roller consists of a disc, cylinder drum, central shaft, pulverizing members, and mounting link. The pulverizing roller was developed for cutting,

mixing, and clod breaking which ultimately pulverizes the soil by impact force. The cutting and clod-breaking action of this unit provides excellent land preparation. The incorporation is done by pulverizing blades welded over rotating drums which were mounted on the single horizontal shaft operated by tractor drawback power. The pulverizing blade runs in a helix pattern from one spike to another in such a way that not more than one portion of



Figure 2: Diagram showing the developed pulverizing roller

a particular blade is in contact with the ground at a time. The beam of pulverizing roller was made up from Ms square pipe material having the dimensions of 60 × 60 × 2125 mm and with 3 mm thickness was fabricated. The peripheral speed of the pulverizing roller was calculated according to the following equations given by Zhang *et al.* (2021):

$$\text{Peripheral Speed (V)} = (\pi D \times N) / 60 \quad \dots(5)$$

Where, D = Roller diameter (0.3 m), N = revolution per minute (300-500 rpm), Therefore the calculated results of peripheral speed of the pulverizing roller was 7.85 m/s for effective pulverization.

Draft Force and Power Requirement

The draft force and draft power of a combined tillage implement is essential for ensuring tractor compatibility and optimizing performance.

Draft Force

Draft force (F_d) is the horizontal force required to pull the implement through the soil. It depends on soil type, implement type, working depth and width, and speed of operation. According to the American Society of Agricultural and Biological Engineers (ASABE), draft force was calculated as empirical formula:

$$F_d = F_i \times W \times d \times \left(1 + \frac{2.3v}{100}\right) \left(1 + \frac{0.25 W_{res}}{W}\right) \quad \dots(6)$$

Where: F_d = Draft force (N), F_i = Soil-specific draft parameter (6 N/cm² for sandy soil, 6 up to 10 N/cm² for clayey soil), W = working width (190cm), d = Working depth (25cm), v = Speed (km/hr), W_{res} = Residue cover (% by weight, 0 if negligible). Therefore, the recommend specific draft coefficient (K), (N/cm², varies with tool type. Hence, cultivator: 5 up to 10 N/cm² and pulverizing roller were 3 up to 5 N/cm². Based on the above formula and given parameters the calculated draft force was 28.5 kN.

Determination Draft Power

Draft power (P_x) is the power needed to overcome

draft force at a given speed. The draft requirement of the tractor-operated combined tillage implement was estimated according to the following equation given by Parmar and Gupta (2016):

$$P_d = (F_d \times v) / 3.6 \quad \dots(7)$$

Where; P_d = draft power required to pull the implement (kW), F_d = draft force (28.5 kN), V = Speed of operation (5 km/hr). Based on the above formula and given parameters the calculated draft power was 39.58 kW.

Determination of Tractor Power

The engine power (P_e) must be higher than draft power due to inefficiencies (traction loss, transmission loss, etc.). Therefore, tractor power required for the operation of combined tillage implement was determined according to the following formula given by Srivastava *et al.* (2006):

$$P_e = P_d / \eta \quad \dots(8)$$

Where: η = Tractive efficiency (0.6 up to 0.8 for the recommended wheeled tractors, for the calculation η = 0.75), P_d = draft Power (39.58 kW). Based on the above formula the calculated tractor power was 52.78 kW (71 HP). Thus, a 75 HP tractor would be suitable for the developed combined tillage implement.

Working Principles of the Implement

The combined tillage implement was developed to streamline secondary tillage by completing it in a single pass, ensuring timely seedbed preparation. It featured a pulverizing roller as the active unit at the rear and cultivator tines as the passive unit at the front. The cultivator tines broke up clods and refined the soil to a fine tilth at the desired working depth, while the pulverizing roller cut, mixed, and further crushed soil clods through impact force, ultimately achieving thorough soil pulverization. The cutting and clod breaking action of this unit provides excellent land preparation and also the pulverizing roller cut and pulverizes the soil for seed bed preparation. Generally, cultivator tines loosen the soil and a rotating blade rotor crushes clods into fine soil, both operations are performed in one tractor pass, saving time and fuel.



Figure 3: Developed prototype during field evaluation of combined tillage implement

Cost Analysis

The cost analysis was conducted in two steps. First, the expenses for materials and fabrication were determined. Second, the operating cost of the developed combined tillage implement was calculated. To assess its financial feasibility, two key parameters were evaluated: fixed costs and variable costs. Fixed costs, such as depreciation, interest, taxes, shelter, and insurance, are based on ownership duration rather than usage. Variable costs, also known as operational costs, fluctuate with machine usage and include repair and maintenance, fuel, lubrication, and labor expenses. The total fabrication cost of the combined tillage was calculated taking into consideration of the materials used and labour charges. The fixed and variable costs for operating the unit per hour were calculated as per the procedure enumerated by IS 9164-1979 test codes and procedures. From the field capacity of the unit, the cost of operation per ha was calculated. The break-even point (BEP), payback period and benefit cost ratio of the tractor drawn combined tillage was estimated.

RESULTS AND DISCUSSION

The development of the combined tillage implement (cultivator with pulverizing roller) involves several critical parameters to ensure structural integrity, operational efficiency, and compatibility with tractor power. The following section provides an in-depth analysis of the main components and their development parameters:

Mainframe

The mainframe holds all components (cultivator tines, pulverizing rollers, three-point hitch) and must withstand bending, tension, and vibrations during operation. The developed frame was lightweight (to reduce cost, soil compaction, and power requirements), strong enough to resist shocks from rough terrain or obstacles and rigid to prevent buckling or collapse under load. Mild steel square pipe ($80 \times 80 \times 2$ mm) was selected for optimal strength-to-weight ratio. Welded joints were used for fixed-end connections to enhance rigidity.

Three-Point Hitch

Function & Design

Connects the implement to the tractor and transmits draft forces. Overall dimension of the developed three point hitch were 2150 mm in length, 1550 mm in width and 1530 mm height and fabricated from MS flat iron for strength and durability.

Cultivator Tines

Function

Breaks clods, pulverizes soil, and uproots weeds at a desired depth and developed as staggered arrangement to prevent clogging by soil/residues. The calculated radius of curvature of the tine was 103.2 mm. The calculated draft force of the tine was 4708.8 N (672.68 N per tine).

Pulverizing Roller

Function

Further pulverizes soil clods via impact and shearing action and it were developed as helical blade arrangement ensures smooth operation. MS square pipe ($60 \times 60 \times 2125$ mm, 3 mm thickness) was used. Therefore, the calculated results of peripheral speed of the pulverizing roller were 7.85 m/s for effective pulverization.

Economic Analysis

The operational cost of tractor-drawn combined tillage was determined as per the procedure enumerated by BIS standard IS 9164-1979 test codes. The total fabrication cost of the combined tillage was 295,000 ETB. The calculated results of fixed and variable costs developed combined tillage were 205.025 and 98.33 ETB/hr, respectively. The costs of operation of tractor-drawn combined tillage were calculated as 1707.43 ETB/hr or 4,084.76 ETB/ha. Hence, the calculated break-even point (BEP), payback period, and benefit-cost ratio of the tractor-drawn combined tillage implements were 1,349.45 hr/yrs, 1.84 yrs, and 4.34, respectively.

CONCLUSIONS

Mechanization in agriculture requires appropriate machinery with a reduction of drudgery for increasing cropping intensity, ensuring timely field operations, and effective application of various crop production inputs utilizing different power sources. This helps in increasing the productivity of land to meet the growing demand for food for the increasing population of Ethiopia. Conventional tillage employs many passes over a field with various soil-turning and soil-pulverizing implements. Such conventional tillage operations require high fuel consumption and contribute to the compaction of soil due to several passes of these implements. This study was undertaken to develop tractor-drawn combine tillage implements. The implement was developed and fabricated at Asella Agricultural Engineering Research Center (AAERC) based on functional, engineering, and cost considerations. Key Assumptions for the development tractor drawn combined tillage are tractor forward speeds of 3 up to 7 km/hr during field testing, soil resistance of 0.25 kg/cm^2 (sandy loam), seven number of tines with 22 cm spacing and working depth 15 cm. Based on the general design requirements the developed implements are simple, safe, and cost-effective construction, compatible with ≥ 55 HP tractors, capable of uniform soil cutting and pulverization. The implements were consists of mainframe, three point hitch, cultivator tines and pulverizing roller. The total fabrication cost of the combined tillage was 295,000 ETB. The calculated results of fixed and variable costs developed combined tillage were 205.025 and 98.33 ETB/hr, respectively. The costs of operation of tractor-drawn combined tillage were calculated as 1707.43 ETB/

hr or 4,084.76 ETB/ha. The calculated break-even point (BEP), payback period, and benefit-cost ratio of the tractor-drawn combined tillage implements were 1,349.45 hr/yrs, 1.84 yrs, and 4.34, respectively. In conclusions, the implement integrates cultivation and pulverization in one pass, optimizing soil preparation while ensuring compatibility with 75 HP tractors for efficient operation. Hence, the developed combined tillage implement presents a cost-effective, efficient, and sustainable solution for Ethiopian agriculture. Policymakers, agricultural extension services, and farmers should collaborate to integrate this technology into national farming systems, ensuring higher productivity, reduced labor, and improved soil management for food security. Based on the above conclusions the developed combined tillage implements can be promote widespread use of the developed tractor-drawn combined tillage implement to reduce multiple passes in conventional tillage, minimize soil compaction, and lower fuel consumption. Encourage small and medium-scale farmers to adopt this technology to enhance timeliness in seedbed preparation and increase cropping intensity. Government and agricultural agencies should subsidize the production and procurement of such implements to make them affordable for Ethiopian farmers. Performance tests of the implement in different soil types to assess adaptability and modify if needed.

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