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Brief Report

Design and construction of portable hand tilling device

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Abstract: This study investigates the design, fabrication, and field evaluation of a portable, manually operated hand tilling device equipped with a fixed rake-like blade and a single guiding wheel. Targeted toward smallholder farmers in low-resource or rural settings, the device was engineered to offer an affordable and sustainable alternative to mechanized tilling tools. Constructed using mild steel for the tilling blade and aluminum alloy for the frame, the unit emphasizes simplicity, robustness, and ease of use. Field experiments were conducted on loamy, sandy, and clayey soil types to assess their performance based on tilling depth, area coverage per minute, and the manual force required for operation. Results showed that in loamy soil, the device achieved a tilling depth of 12 cm and covered 1.5 m^2/min using a pushing force of 45 N. Sandy soil conditions allowed for 1.8 m^2/min coverage at a slightly reduced depth of 10 cm with only 35 N of effort, indicating optimal performance in light soils. Conversely, clayey soil presented a more challenging environment, where tilling depth decreased to 8 cm and area coverage to 1.2 m^2/min, with the highest force requirement of 50 N—still within ergonomic thresholds set by ISO 11228-1. The consistent structural integrity and ergonomic compliance across soil types validate the device's utility in real-world farming scenarios. While particularly effective in loamy and sandy terrains, its limitations in high-resistance soils highlight potential areas for design refinement. Overall, the study underscores the device's promise as a low-tech, high-impact agricultural solution for small-scale farming systems, contributing to sustainable agricultural development and local food security.

Keywords: portable hand tiller; manual agricultural tool; soil tillage device; fixed rake blade; ergonomic farm equipment

1. Introduction

Agriculture has long served as the foundation of human civilization, ensuring food security and economic development. In countries like Nigeria, smallholder farmers represent a substantial portion of the agricultural workforce. However, these farmers typically depend on traditional tools such as hoes and cutlasses for land preparation. While affordable and accessible, these tools are labor-intensive and time-consuming [1]. In contrast, mechanized farming equipment in developed nations has significantly boosted productivity. Yet, due to high costs and complex maintenance, such equipment remains largely inaccessible to small-scale farmers in developing regions [2].

To bridge this technological divide, the development of affordable, efficient, and user-friendly tools tailored to the needs of smallholder farmers is essential. Portable hand tilling devices offer a promising solution by combining the simplicity of traditional tools with the improved efficiency of mechanized equipment. These devices can help reduce the physical burden on farmers while enhancing the effectiveness of land preparation [3].

Despite the importance of proper land preparation in crop production, many smallholder farmers lack access to appropriate tools. The limitations of traditional methods reduce the area that can be cultivated, negatively impacting food security and income generation [4]. Furthermore, improper tilling techniques can degrade soil quality and reduce yields [5]. Thus, a cost-effective, ergonomically designed, and soil-adaptable portable tilling device is critically needed, particularly in regions like Nigeria.

This project aims to design and construct a portable hand-tilling device to address the challenges faced by smallholder farmers. The specific objectives are to develop a lightweight, durable tilling tool using locally available materials, to ensure ergonomic design that reduces user fatigue, and to finally test performance across different soil types and conditions.

Successful development of such a device could revolutionize small-scale farming by enabling farmers to till larger areas with less effort, leading to increased crop production and improved livelihoods [6]. Additionally, it can support sustainable agriculture by reducing soil compaction and maintaining soil health [7].

This study focuses on the design, construction, and initial testing of the device for smallholder farmers in Nigeria. Evaluation parameters include mechanical performance, ergonomic suitability, and adaptability to local soils. Limitations of the study include the scale of field testing and the lack of long-term durability assessments, which are recommended for future research.

1.1. Traditional tilling methods

Most smallholder farmers rely on hoes and cutlasses due to their low cost and availability [8]. However, these tools require significant manual effort and often result in uneven soil preparation, negatively affecting germination and crop yield [9].

1.2. Mechanized tilling equipment

Mechanized options like tractors and power tillers offer speed and efficiency but are not viable for many smallholder farmers due to high costs, maintenance demands, and the need for technical skills [10, 11]. Additionally, heavy machinery can lead to soil compaction and reduce long-term soil productivity [12].

1.3. Portable hand tilling devices

Portable tilling devices strike a balance between traditional and mechanized tools. For example, Girish [13] designed a hand-operated plow that reduced physical strain and improved posture, while Saxena [2] developed a cost-effective motorized tiller. These innovations show that compact tools can significantly improve small-scale farming [14].

1.4. Ergonomic design

Ergonomics plays a vital role in tool adoption. Features such as adjustable handles, balanced weight, and user-friendly controls minimize fatigue and injury risks [15]. Ergonomically designed tools are more likely to be adopted and effectively used by farmers [16].

1.5. Material selection

Using locally sourced materials ensures affordability and ease of repair. Ajayi and Adetola [3] demonstrated this by constructing a hand-push rotary hoe with readily available components, proving the practicality of cost-effective fabrication [1,17].

1.6. Soil adaptability

Soil characteristics like texture, moisture, and compaction levels significantly affect tiller performance. Devices must be adjustable and robust enough to perform effectively across various soil types commonly found in Nigeria [14,18].

1.7. Environmental sustainability

Lightweight, manually operated, or battery-powered devices reduce soil compaction and greenhouse gas emissions compared to fossil-fuel-powered machines. This makes them environmentally sustainable and suitable for conservation-focused agriculture [5,18].

1.8. Economic impact

Affordable and efficient tools can enhance productivity and income for smallholder farmers. Studies show that appropriate technologies increase yields and improve access to markets [9, 15]. For example, Raju et al. [5] developed an eco-friendly hybrid tiller, while Lane patented a user-friendly handheld tiller—both aimed at small-scale agriculture [19].

Despite progress, challenges remain in scaling, training, and maintenance. Future work should focus on extended field testing, incorporating user feedback, and exploring new materials and power options to improve performance and adoption [18].

2. Material and method

The conceptual design of the portable hand tilling device integrates simplicity, ergonomics, and mechanical efficiency to assist smallholder farmers in soil preparation tasks. The device features a manually operated frame constructed from lightweight yet durable materials such as mild steel, ensuring ease of use and portability while also maintaining robustness for long-term use. It incorporates a fixed rake-like tilling blade mounted on a central axle, which is powered by direct hand pushing, significantly reducing user fatigue and promoting better control over the tilling process. The overall design prioritizes low-cost fabrication using locally available materials, ensuring that the device is both affordable and easily repairable. Its minimal environmental impact, coupled with its focus on sustainability, makes it an ideal solution for small-scale farmers in rural communities, fostering improved agricultural productivity and promoting environmentally responsible farming practices.

2.1. Engineering design

The portable hand tilling device is designed to assist in small-scale agricultural soil preparation. It consists of a fixed, rake-like blade powered by direct hand push, eliminating the need for external energy sources. The design focuses on ergonomics, efficiency, and durability.

2.1.1. Design specifications

Blade material: High-carbon steel (for durability and wear resistance).

Handle material: Lightweight aluminum or fiber-reinforced polymer (for ease of use).

Blade angle (θ): 30°–45° (optimal penetration angle).

Working width (W): 15–20 cm (for manageable soil coverage).

Weight: ≤ 3 kg (for portability).

2.1.2. Force analysis and tillage resistance

The force required to push the tiller into the soil depends on soil resistance and blade geometry. The soil resistance force F_{soil} is given by:

$$F_{\text{soil}} = k \times A \times d \tag{1}$$

where k is the soil penetration resistance coefficient (N/cm^2) [20], A is the effective blade area (cm^2), and d is the tillage depth (cm).

The effective blade area A is calculated as:

$$A = W \times d \times \sin(\theta) \tag{2}$$

The total pushing force F_{push} required from the operator must overcome F_{soil} and frictional resistance F_{friction}:

$$F_{\text{oush}} = F_{\text{soil}} + F_{\text{friction}} \tag{3}$$

where $F_{\text{friction}} = \mu \times N$, with μ as the coefficient of friction between soil and blade, and N as the normal force [21].

2.1.3. Handle design and ergonomics

The handle length L is optimized for minimal operator bending, using anthropometric data. The recommended handle height H is:

$$H = 0.4 \times \text{User Height} \tag{4}$$

The force applied by the operator should not exceed 50 N for prolonged use to prevent fatigue [22].

2.1.4. Structural integrity and blade stability

The blade must withstand bending stresses. The bending stress σ_b is calculated as:

$$\sigma_b = \frac{M \times y}{I} \tag{5}$$

where M is the bending moment $F_{\text{push}} \times L$, y is the distance from the neutral axis, and I is the moment of inertia of the blade cross-section [23].

The safety factor (SF) is ensured by:

$$SF = \frac{\sigma_{\text{yield}}}{\sigma_b} \tag{6}$$

The portable hand tilling device is designed for efficient soil penetration with minimal operator effort. The fixed rake-like blade ensures consistent tillage depth, while ergonomic considerations enhance usability. This design ensures a functional, durable, and user-friendly hand tiller for small-scale farming applications.

3. Construction

The construction of the portable hand tilling device was carried out through a series of well-defined steps involving material selection, cutting, assembly, and final finishing. The device consisted of a metal frame, a single front wheel, a fixed rake-like blade, and a handle for manual pushing.

3.1. Material selection

Mild steel was selected for the frame due to its strength, durability, and ease of fabrication. The blade was made from high-carbon steel to ensure sufficient hardness and wear resistance during soil penetration. A solid rubber wheel with a metal hub was chosen for the front support.

3.2. Frame fabrication

The frame was fabricated using square hollow mild steel pipes of 25 mm × 25 mm cross-section. The pipes were measured, marked, and cut using a metal-cutting saw to the required lengths for the main support, handle bars, and front fork. The pieces were then joined by arc welding, forming a rigid T-shaped structure that included vertical and horizontal supports.

3.3. Wheel installation

A fork was fabricated from bent mild steel flat bars and welded to the front of the frame to hold the wheel. A steel rod served as the axle and was inserted through the wheel hub and fork ends. Locking nuts and washers were used to secure the wheel, allowing free rotation.

3.4. Blade mounting

A rake-like blade with six uniformly spaced prongs was prepared by machining a flat high-carbon steel strip. The prongs were ground to pointed ends for easier soil penetration. This blade was welded to the lower end of the main frame at an inclined angle to ensure efficient tilling as the device moved forward.

3.5. Handle assembly

Two hollow pipes were welded to the upper rear of the frame to act as push handles. Rubber grips were installed on the handles to provide better user comfort and control.

3.6. Surface finishing

All welded joints were ground smooth, and the entire structure was cleaned using a wire brush. A primer coat was applied to prevent rust, followed by two coats of anti-corrosive black paint for durability and aesthetic appearance.

3.7. Testing and adjustments

After assembly, the device was tested on a prepared field surface. Minor adjustments were made to the blade angle and wheel alignment to improve efficiency and balance during operation. **Figure 1** shows the hand tilling machine after construction.

Figure 1. Hand tilling device after construction.

4. Experiment test procedure

The experimental test of the portable hand tilling device with a fixed rake-like blade and a single front wheel powered by direct hand push was conducted to evaluate its field performance across different soil types. The procedure followed the steps below:

i. Test environment preparation: Three distinct soil plots (loamy, sandy, and clayey soils) of dimensions 10 m × 2 m were selected in an open agricultural field. Each plot was cleared of debris and leveled to ensure consistent test conditions.
ii. Device pre-checks: The hand tilling device was inspected for mechanical integrity, and all nuts and bolts were tightened. The fixed rake blade was examined for sharpness and properly aligned to the wheel axis.
iii. Test execution:
    - The device operator was briefed and calibrated using standard body posture and pushing method based on ISO 11228-1 ergonomics guidelines.
    - The device was pushed manually across each soil type a constant pace to ensure uniformity.

- For each soil type, three trials were conducted, and average values were taken for accuracy.

iv. Measured parameters:
- Tilling depth was measured using a calibrated soil depth probe at five points along the tilled line.
- Area covered per minute was calculated using a stopwatch and measured width and distance covered.
- Force required was measured using a spring balance attached to the handle, monitored during motion.

v. Data recording: All measurements were recorded on-site and later tabulated for analysis.

Table 1 presents the overall test results obtained from evaluating the hand tilling device on different soil types. It includes key performance indicators such as tilling depth, area covered per minute, and the force required for manual operation. These metrics were measured across loamy, sandy, and clayey soils to assess the device's adaptability and effectiveness under varying conditions. The data highlights how soil texture and density influence both the depth of penetration and the effort needed for tilling. This comprehensive overview provides a basis for analyzing the device's suitability for specific agricultural environments.

Table 1. Test results.

Soil type	Tilling depth (cm)	Area covered (m^2/min)	Force required (N)
Loamy	12	1.5	45
Sandy	10	1.8	35
Clayey	8	1.2	50

Table 1 presents the overall test results obtained from evaluating the performance of the hand tilling device across different soil types. It summarizes key parameters such as tilling depth, area covered per minute, and the manual force required during operation. These results provide a comprehensive overview of how soil texture and composition influence the efficiency and usability of the device. **Figure 2** shows the Performance of the hand tilling device on different soil types.

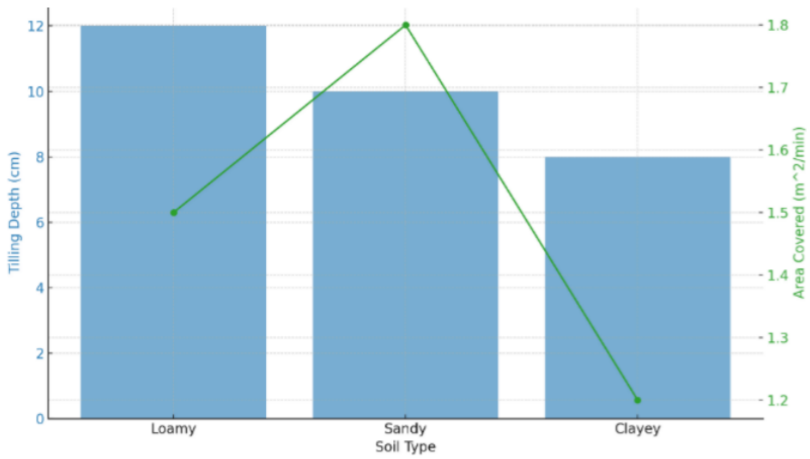

Figure 2. Performance of the hand tilling device on different soil types.

5. Discussion

To enhance the reliability of the performance evaluation, the experiment was conducted using a Completely Randomized Design (CRD). Soil treatments—loamy, sandy, and clayey—were randomly assigned to uniform test plots to reduce bias and isolate the effect of soil type on device performance. Each treatment was replicated three times to account for variability and ensure statistical robustness. The uniformity of environmental and testing conditions justified the use of CRD, as it minimized the influence of external factors such as slope, moisture variation, or operator fatigue.

Table 1 presents the overall test results of the hand tilling device under three typical soil conditions. The outcomes demonstrate the functionality and relative efficiency of the manually operated tool across varying soil textures, highlighting differences in tilling depth, area coverage, and force required for operation.

In loamy soil, known for its balanced texture and moderate resistance, the device achieved the maximum tilling depth of 12 cm and a moderate area coverage of 1.5 m^2/min, requiring a pushing force of 45 N. This confirms its suitability for medium-density soils where effective penetration can be attained with manageable physical input.

In sandy soil, characterized by low cohesion and minimal resistance, the tilling depth was slightly reduced to 10 cm, but the device achieved the highest area coverage of 1.8 m^2/min. It also required the least force of 35 N, indicating smooth operation in light-textured, loosely packed soil. This suggests optimal performance in conditions where speed and coverage are prioritized over depth.

Conversely, clayey soil presented the greatest challenge. The device recorded the lowest tilling depth of 8 cm, the smallest area coverage of 1.2 m^2/min, and required the highest force of 50 N. Although this value still falls within the ergonomic limit specified by ISO 11228-1 for manual handling, it highlights the increased effort needed to till dense and cohesive soils.

Despite performance variations across soil types, the device remained structurally consistent. The mild steel blade withstood repeated mechanical impact, and the aluminum alloy frame contributed to lightweight maneuverability. Importantly, all force values remained below the ergonomic threshold of 50 N, affirming the device's user-friendly and safe design for manual agricultural tasks.

These findings are consistent with previous research. For instance, Badu et al. [1] reported optimal tilling results in loamy soils, while Ajayi and Adetola [3] highlighted performance difficulties in clay-dominated terrains. The data validates the utility of this low-tech tilling device in smallholder farming, especially in loamy and sandy areas where mechanized equipment may be impractical or unaffordable.

In conclusion, the integration of a CRD experimental setup and the observed performance metrics collectively underscore the viability of the device for resource-constrained agricultural settings. The device demonstrates potential for further development and field deployment, and future studies may consider alternative blade geometries or adjustable depth settings to improve performance in high-resistance soils like clay.

6. Conclusion

The experimental analysis of the manually operated hand tilling device confirms its capability to deliver efficient soil preparation under real field conditions. It achieved tilling depths between 8 and 12 cm and area coverage rates ranging from 1.2 to 1.8 m^2/min, depending on the soil type. Loamy and sandy soils offered favorable conditions for device performance, requiring only 35–45 N of manual force, while clayey soil demanded slightly more effort at 50 N. The use of mild steel for the blade and lightweight aluminum alloy for the structural frame provided a balance between durability and maneuverability. The inclusion of a single front wheel enhanced directional control, making the device easy to operate even on uneven terrain. All operations were powered solely by human force, eliminating the need for external energy sources and making the tool ideal for small-scale, off-grid agricultural settings. While performance in clayey soils was less optimal, the force requirement remained within acceptable ergonomic limits. Enhancements such as adjustable blade depth, ergonomic handles, or mechanical advantage through lever arms could improve its suitability for heavier soils. In summary, the portable hand tiller offers a cost-effective, eco-friendly solution for smallholder farmers, fulfilling key design goals related to efficiency, usability, and structural resilience. This study validates its utility and opens opportunities for iterative design improvements based on specific soil conditions.

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Conflict of interest: The author declares no conflict of interest.

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