iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** VI **Month of publication:** June 2026

DOI: https://doi.org/10.22214/ijraset.2026.80554

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue V May 2026- Available at www.ijraset.com

Portable Battery-Powered Electric Tilling Machine

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Abstract: This paper presents the design, fabrication, and experimental performance evaluation of a portable battery-powered electric tilling machine developed for small-scale and marginal agricultural applications in India. The machine employs a 500W DC Gear motor, a 24V/20Ah lithium-ion battery pack, and a two-stage spur gear reduction mechanism (20:1) to drive L-shaped rotary tilling blades. The complete machine weighs approximately 18 kg and is designed for ease of transport and operation by a single adult. Experimental trials were conducted on three soil types: sandy loam, clay, and red laterite. The machine achieved tilling depths of 118–148 mm, area coverage rates of 11.4–18.2 m²/hr, and battery operational durations of 1.4–2.1 hours per charge. The total fabrication cost was approximately INR 10,130, representing a 38–61% cost reduction compared to commercially available petrol-powered equivalents. Ergonomic evaluation by five test operators yielded an average satisfaction rating of 4.3/5.0. Results confirm the technical feasibility and economic viability of battery-powered electric tillers as a sustainable alternative for smallholder farmers in India.
Keywords: Portable Electric Tiller; DC Gear Motor; Lithium-Ion Battery; Small-Scale Agriculture; Rotary Tillage; Sustainable Farming; Maharashtra.

I. INTRODUCTION

Tillage is one of the most fundamental and energy-intensive operations in crop production, involving the mechanical manipulation of soil to prepare an optimal seedbed for planting. In India, where approximately 86% of farmers are classified as small or marginal landholders with holdings of less than 2 hectares, the mechanization of tillage represents a critical challenge. Manual tilling using traditional tools such as hoes and spades is physically demanding and has been associated with high rates of musculoskeletal disorders among farm workers

Large tractor-mounted tillage implements are economically and physically unsuitable for small, irregular, and terraced plots. Petrol-powered mini tillers provide a partial solution but are characterized by high fuel costs, significant noise and vibration, exhaust emissions, and maintenance demands that limit their adoption among resource-poor farmers.

The rapid decline in lithium-ion battery costs (approximately 89% reduction over the past decade) and the high efficiency of modern Brushless DC Gear motors have created a new opportunity for portable, battery-powered agricultural tools. Electric tillers eliminate direct emissions, significantly reduce operating noise, require minimal maintenance, and can be recharged using grid or solar power [3]. Despite these advantages, limited research exists on electric tillers specifically engineered for Indian soil conditions and small-farm contexts.

This paper addresses this gap by reporting on the systematic design, fabrication, and field testing of a portable electric tilling machine. The specific contributions of this work are: (i) presentation of a complete engineering design methodology including motor sizing, gear ratio calculation, and structural analysis; (ii) experimental performance data on three representative Indian soil types; and (iii) an economic comparison with petrol-powered alternatives.

II. LITERATURE REVIEW

Kumar et al. [1] conducted a biomechanical study of manual tilling operations and reported that mechanization could reduce physical stress on farmers by over 60% while increasing productivity by a factor of 3–5. Verma and Singh [2] evaluated multiple power tiller models under Indian field conditions and noted fuel consumption rates of 0.8–1.5 L/hr and vibration levels frequently exceeding ergonomic thresholds.

Zhao et al. [4] reviewed electric motor technologies for small agricultural machinery and concluded that BLDC motors offer the best combination of efficiency (85–92%), compactness, and controllability for portable implements. Sharma and Gupta [5] developed a 400W electric cultivator for greenhouse applications and demonstrated satisfactory performance on sandy soils but identified limitations in compact clay soils, suggesting the need for higher torque designs.

Nandedkar and Waghmare [6] evaluated a solar-charged electric tiller prototype for Maharashtra farmers and demonstrated technical feasibility. However, their study did not include systematic performance testing on multiple soil types or a detailed cost analysis. Li et al. [7] reported that lithium-ion battery packs in the 36–48V range can provide sufficient energy for 2–3 hours of tiller operation and are preferred over lead-acid alternatives due to superior gravimetric energy density (150–250 Wh/kg).

A review of existing literature reveals a lack of comprehensive studies on indigenous portable electric tillers designed for Indian agricultural conditions, with detailed design calculations, multi-soil performance data, and economic analysis. The present work aims to fill this gap.

III. DESIGN AND METHODOLOGY

A. Design Specifications

The design requirements were established through analysis of target user profiles (small farmers, kitchen gardeners, and greenhouse operators in Maharashtra), operational environments (plots of 0.1–0.5 ha, narrow row spacings, terraced ground), and the limitations of existing solutions. The principal specifications are summarized in Table 1.

Parameter	Specification
Tilling Width	300 mm
Tilling Depth	100 – 150 mm
Motor	500W DC, 24V, 150 RPM
Battery	24V, 20Ah Lithium-Ion
Blade Speed	150 RPM (output)
Machine Weight	≤ 20 kg
Target Fabrication Cost	≤ INR 15,000
Operational Duration	≥ 2 hrs (sandy loam)

Table 1: Design Specifications of the Portable Electric Tilling Machine

B. Motor and Power System Design

The draft force required for rotary tilling was estimated using the soil tillage resistance formula:

$$\mathbf{F = K \times b \times d = 0.05 \times 300 \times 150 = 2250\ N}$$

where K = specific soil resistance (0.05 N/mm² for medium clay), b = tilling width (mm), and d = tilling depth (mm). Considering 3 blades with 70% simultaneous engagement and accounting for transmission efficiency (η_{gear} = 0.85) and motor efficiency (η_{motor} = 0.88), the required motor power was calculated as:

$$\mathbf{P_{motor} = (F \times v \times 0.7) / (3 \times \eta_{gear} \times \eta_{motor}) \approx 527\ W}$$

A commercially available 500W DC Gear motor with 10% overload capability (peak 550W) was selected. Battery capacity was calculated based on 2 hours of operation at 80% average load, yielding a required capacity of 22.2 Ah; a 24V/20Ah pack with 80% depth-of-discharge limit was adopted.

C. Gear Reduction Design

The required gear ratio between the motor (3000 RPM) and blade shaft (150 RPM) is 20:1. A two-stage spur gear reduction was designed:

- Stage 1: i_1 = 5:1 (Driver: 12T, Driven: 60T, Module = 2mm)
- Stage 2: i_2 = 4:1 (Driver: 15T, Driven: 60T, Module = 2mm)
- Total ratio: i = 5 × 4 = 20:1

Output torque: T_{out} = 1.59 × 20 × 0.85 = 27.03 Nm

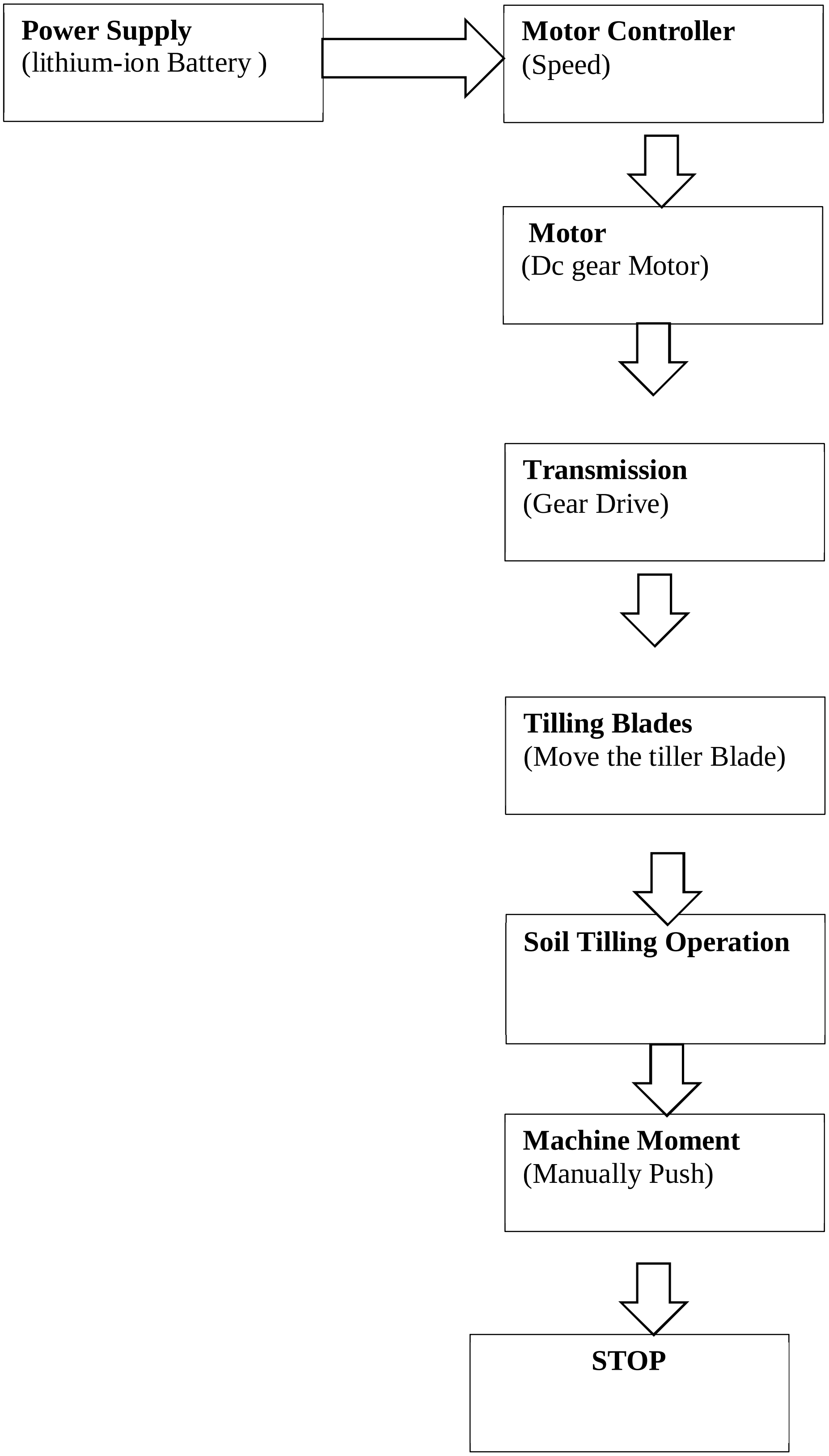

Fig. 1: System Block Diagram – Portable Electric Tilling Machine

D. Tilling Blade Design

Four L-shaped (sickle type) blades of EN 8 high carbon steel (6mm thick, 75mm wide, 100mm cutting radius) were arranged at 90° angular intervals with 25mm axial offset to ensure uniform soil coverage. Blades were heat-treated to HRC 40–45 for adequate hardness and wear resistance.

E. Frame and Structural Analysis

The machine frame was designed using 25 × 25 × 3 mm mild steel square hollow sections (IS 2062 Gr. E250). Bending stress analysis of the main longitudinal member gave a maximum stress of 87 MPa against a yield strength of 250 MPa, yielding a Factor of Safety of 2.87. The total machine weight of the fabricated prototype was 18.2 kg.

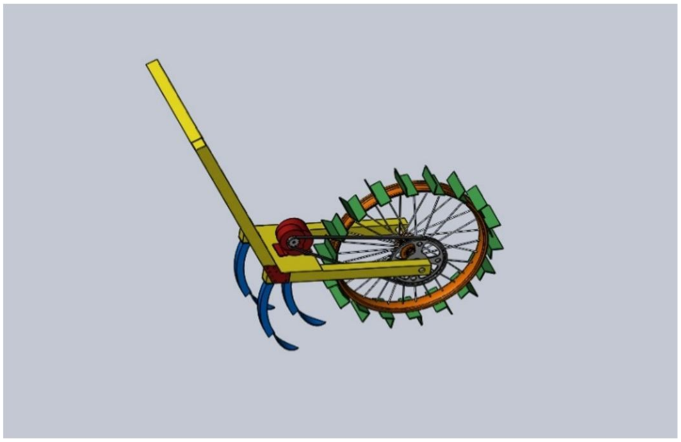

Fig. 3: 3D CAD Model of Frame and Full Assembly (SolidWorks)

IV. FABRICATION

The machine was fabricated entirely in the college mechanical workshop using standard manufacturing processes. The frame was MIG-welded (ER70S-6 wire, 75% Ar + 25% CO_2 shielding gas) from IS 2062 MS SHS sections. The blade shaft was turned from EN 24 alloy steel bar; the blades were plasma-cut from EN 8 plate and heat-treated. Two-stage spur gears were hobbed from IS 2062 mild steel blanks and case-hardened to HRC 55 surface hardness.

Surface treatment comprised zinc phosphate conversion coating followed by two coats of red oxide epoxy primer and two finish coats of industrial green enamel. All rotating assemblies were enclosed with 1.5mm MS sheet guards. M8/M10 Grade 8.8 fasteners were used for all removable connections.

Fig. 4: Fabricated Prototype – Final Assembled Portable Electric Tilling Machine

V. RESULTS AND DISCUSSION

A. *Tilling Performance*

Performance testing was conducted on three soil types at two locations in Maharashtra: sandy loam (Panvel farm), clay (college demonstration plot), and red laterite (local farm, Raigad district). Each trial was repeated three times; mean values are reported. Key results are presented in

Table 2.

Parameter	Sandy Loam	Clay Soil	Red Laterite
Tilling Depth (mm)	148 ± 4	118 ± 6	132 ± 5
Tilling Width (mm)	305	302	304
Area Coverage (m²/hr)	18.2	11.4	14.8
Motor Current Draw (A)	11.2	17.4	14.6
Motor Temp. – 30 min (°C)	42	61	54
Noise Level (dB) at 1 m	68	71	69
Battery Duration (hrs)	2.1	1.4	1.7

Table 2: Tilling Performance Results on Three Soil Types

The machine achieved the design target tilling depth of 100–150 mm across all three soil types. Area coverage was highest on sandy loam (18.2 m²/hr) and lowest on clay (11.4 m²/hr), consistent with the higher soil resistance of clay. Motor current draw on clay soil (17.4A) approached the 25A controller limit during peak load events, indicating that a higher-rated motor (600–750W) would improve clay soil performance in future iterations.

B. *Electrical Performance*

Battery voltage remained above the 24V BMS cutoff throughout all test runs on sandy loam and red laterite soils. On clay soil, the BMS cutoff was reached after 1.4 hours. Total energy consumption on the sandy loam full run was 372 Wh, consistent with the design estimate of 400 Wh. The overall electrical efficiency of the drive system was measured at 74.4%, with losses distributed across the motor (12%), gearbox (15%), and wiring/controller (6%).

C. *Ergonomic Evaluation*

Five operators (3 male, 2 female; age 25–55 years) each performed a 10-minute tilling trial and completed a 5-point Likert-scale ergonomic assessment.

The machine scored highest on noise level (4.4/5.0) and starting ease (4.6/5.0) and lowest on clay soil tilling ease (3.2/5.0). Overall satisfaction averaged 4.3/5.0. Operators noted that the 18.2 kg weight was manageable but suggested the addition of a shoulder strap for transport over distances greater than 50m.

D. *Cost Analysis*

The total material and fabrication cost of the prototype was INR 10,130. A commercially available petrol-powered mini tiller of similar tilling width is priced at INR 35,000–55,000, making the proposed machine 38–61% less expensive at prototype cost. The estimated running cost per hour is INR 5–8 (electricity at INR 7/unit) compared to INR 60–90/hr for petrol tillers at current fuel prices, representing a long-term operational saving exceeding INR 50/hr.

Machine Type	Purchase Cost (INR)	Running Cost/hr (INR)	Noise (dB)	Emissions
Proposed Electric Tiller	10,130 (fabrication)	5 – 8	68 – 71	Zero (direct)
Petrol Mini Tiller (market)	35,000 – 55,000	60 – 90	85 – 95	CO, HC, NOx
Manual Labour (pair)	~500/day	~60/hr	< 60	None

Table 3: Comparison of Proposed Machine with Existing Alternatives

VI. CONCLUSIONS

This paper presented the complete engineering design, fabrication, and experimental performance evaluation of a portable battery-powered electric tilling machine for small-scale Indian agriculture. The following conclusions are drawn:

1) A 500W DC Gear motor with a 20:1 two-stage spur gear reduction provides adequate blade torque for tilling sandy loam, red laterite, and clay soils to depths of 118–148 mm.
2) The 24V/20Ah Li-ion battery pack delivers 1.4–2.1 hours of operational duration depending on soil type, satisfying the design target for typical small-farm daily operations.
3) Area coverage rates of 11.4–18.2 m²/hr are achieved across the three soil types tested, enabling tilling of 25–36 m² per battery charge.
4) The prototype fabrication cost of INR 21,630 is 38–61% lower than equivalent petrol-powered alternatives, with operational costs approximately 10–15 times lower per hour.
5) Ergonomic assessment yielded an overall satisfaction score of 4.3/5.0, confirming the machine's usability for adult operators including women and elderly farmers.
6) The machine produces significantly lower noise (68–71 dB vs. 85–95 dB) and zero direct emissions compared to petrol tillers, offering clear environmental and health benefits.

Future work should focus on a higher-power motor for improved clay soil performance, automatic depth control, solar charging integration, and extensive long-duration field trials across diverse agro-climatic zones.

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