

## Weeding Rake Design, Fabrication and Performance Evaluation

Rabiu Ahmad Abubakar

Department of Agriculture and Bio-Environmental Engineering Technology, Audu Bako College of Agriculture Dambatta, PMB 3159, Kano State, Nigeria

### ABSTRACT

This study focused on the design, fabrication, and performance evaluation of a hand-push weeding rake equipped with a single front wheel. The device was developed to provide a cost-effective and environmentally friendly alternative to herbicide application for smallholder farmers. Performance evaluation was conducted across three soil types (sandy, loamy, and clay), with measurements of operational time, weeding efficiency, and human energy expenditure. The results indicated that soil type significantly influenced performance. Sandy soil required the least operational time (12.8 min) and energy input (245.3 kJ) but achieved moderate efficiency (87.6%). Loamy soil recorded the highest efficiency (92.4%) with intermediate energy expenditure (312.7 kJ). Conversely, clay soils presented the greatest operational resistance, leading to higher time (21.8 min), lower efficiency (79.6%), and higher energy demand (358.1 kJ). Statistical analysis using ANOVA confirmed significant differences ( $p < 0.0001$ ) in all measured parameters across soil types. Tukey's post-hoc tests further revealed that all pairwise soil comparisons were statistically significant. The findings demonstrate that the single-wheel weeding rake is best suited for loamy soils, though it can function effectively in sandy soils with reduced efficiency. Clay soils remain a challenge due to higher energy requirements. While the study was limited to controlled test plots, the results underscore the potential of this tool as a low-cost, sustainable, and ergonomic alternative to chemical weed control methods for small-scale farming systems.

### \*Corresponding author

Rabiu Ahmad Abubakar, Department of Agriculture and Bio-Environmental Engineering Technology, Audu Bako College of Agriculture Dambatta, PMB 3159, Kano State, Nigeria.

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### Introduction

Weed control remains one of the most labor-intensive, time-critical, and yield-limiting operations in smallholder and peri-urban cropping systems across the tropics. In rain-fed cereals, pulses, and horticultural beds, early-season weed pressure can reduce yields by 20-60% if unmanaged, with global syntheses estimating double-digit average losses to weeds even under modern management [1]. Although herbicides can be effective, their affordability, safe use, and ecological compatibility are frequent barriers for smallholders, while the accelerating spread of herbicide-resistant biotypes undermines long-term efficacy [2,3]. Consequently, low-cost, human-powered mechanical weeders remain essential to integrated weed management (IWM), providing timely, selective disruption of intra-row and inter-row weeds with minimal capital investment, reduced environmental externalities, and improved soil surface condition via shallow loosening or mulching.

Among human-powered implements, wheel-supported push-pull weeders, "wheel hoes," and rakes continue to evolve to reduce drudgery and increase field capacity for smallholder contexts where engine power is scarce or plots are too small for tractor access [4,5]. A single-front-wheel configuration is attractive for narrow beds and tight headlands: the wheel stabilizes depth and guides the toolpath, while a trailing or mid-mounted rake/weeding blade disrupts shallow weed roots with limited soil inversion,

preserving moisture and structure. However, the performance envelope of such tools depends sensitively on (i) geometric design (wheel diameter, tool width, tool-soil working angle), (ii) human factors (handle height, handle diameter/shape, push-pull force), and (iii) soil and crop conditions (texture, moisture, intra-row spacing). Optimizing these aspects through structured design-fabrication-testing is crucial to deliver measurable gains in weeding efficiency, effective field capacity, energy cost, and operator comfort/safety.

This paper presents the design, fabrication, and performance evaluation of a hand-push weeding rake with a single front wheel, engineered for low-cost manufacture and ergonomic use in smallholder plots. The introduction (this section) frames the need, summarizes relevant agronomic, mechanical, and ergonomic literature, and defines the performance metrics and design criteria underpinning the prototype.

### Agronomic and Socio-Economic Need

Weeds compete with crops for light, nutrients, and water; they impede harvest operations and harbor pests; and where labor bottlenecks delay weeding 2-4 weeks after emergence, losses compound quickly [1]. In sub-Saharan Africa and South/Southeast Asia, hand weeding by sickle or hoe remains dominant, undertaken largely by women and hired labor, often in stooped or squatting postures that increase musculoskeletal strain and limit daily output [4,6,7]. Herbicides can reduce labor but bring challenges of cost, supply reliability, resistance management, off-target effects, and training requirements [2,3,8], motivating mechanical IWM options that are cheap, maintainable, and robust in heterogeneous fields.

### Role of Human-Powered Mechanical Weeders

Human-powered push-pull weeders and rakes can deliver high weeding efficiency at shallow working depths (10-25 mm), severing or uprooting young weeds and forming a loose mulch that suppresses new emergence while minimizing soil disturbance [4,5,9]. Participatory evaluations in lowland rice and upland systems report substantial reductions in drudgery and time per hectare when designs match row spacing and soil moisture windows [4,10,11]. Yet, many legacy designs suffer from suboptimal ergonomics (poor handle height/diameter and grip posture), excess draft, or inadequate guidance, which together reduce field capacity and increase operator fatigue [6,12,13]. A wheel-guided architecture offers steadier depth control and direction stability, translating more of the operator's effort into effective soil-weed disruption.

### Why a Single-Front-Wheel Weeding Rake?

Compared to twin-wheel frames, a single front wheel reduces mass and simplifies fabrication, improving maneuverability in narrow beds and around crop stands. It allows short turns on small headlands and follows minor micro-topography without jamming. The trade-off is a potentially higher demand on the operator to maintain lateral balance and a need for careful alignment of the rake/blade behind the wheel track to avoid crop damage. These trade-offs can be managed through geometry (wheel diameter and trail), handle design (height and sweep), and rake/blade presentation angle, coupled with an adjustable skimming depth. The goal is to achieve (i) acceptable specific draft on typical loams, (ii) high weeding efficiency on 2-4-leaf weeds, and (iii) operator forces within ergonomic guidelines for pushing/pulling sustained over 30-60 minutes [12,14,15].

### Yield loss and the Imperative for Timely Weeding

Oerke's global synthesis highlights that weeds remain among the largest sources of avoidable crop loss despite technological advances, with average preventable losses often exceeding those from diseases or insects [1]. In smallholder rice systems, Rodenburg et al. emphasize the **Criticality of Early Mechanical Weeding** to limit yield reduction and to complement selective herbicides within IWM [4]. In West Africa and South Asia, participatory trials show that **Mechanical Weeders** can match or exceed hand weeding in cost-effectiveness when row spacing is consistent and timely passes are made at early stages [4,10].

Meanwhile, herbicide resistance has proliferated-Heap documents the expansion of resistant species and mechanisms globally, underscoring the need for non-chemical methods to preserve herbicide efficacy [2]. Beyond resistance, emerging evidence suggests possible soil microbial community shifts associated with repeated herbicide use, providing another rationale for diversifying tactics [8]. Collectively, these studies justify renewed attention to well-designed manual weeders as first-line or complementary tools.

### Mechanical Weeders: Tool-Soil Interaction and Field Performance

Classical and contemporary studies evaluate blade/rake geometries, soil engagement angles, and field performance metrics for manual weeders. Tewari et al. analyzed weeding devices considering both ergonomics and mechanical behavior, linking energy expenditure and output across tools and postures [6]. Their later work on push-pull weeder blades in field conditions provided evidence for the sensitivity of weeding efficiency and draft to blade geometry and operating parameters [5]. Participatory assessments of mechanical weeders in lowland rice (e.g., stirrup, loop, and cono weeders)

reported that tool choice and performance are context dependent, varying with puddling status, soil texture, and row spacing [10,11].

Performance is typically quantified by weeding efficiency (% weeds removed or suppressed), effective field capacity (ha h<sup>-1</sup>), field efficiency (% of theoretical capacity realized, including turns/adjustments), specific draft (kN m<sup>-1</sup> tool width), and energy cost (kJ m<sup>-2</sup>) linked to operator physiology [5,6,9,11]. Shallow, slicing engagement tends to minimize draft and energy cost but requires precise depth control and sharp edges; rake-type implements add combing and soil-breaking action that can enhance uprooting of thread-stage weeds while leaving a porous surface that reduces crusting.

### Ergonomics of Push-Pull Tools and Handle Design

Operator acceptance and sustainable use hinge on ergonomic fit. Several lines of evidence guide human-tool interface decisions:

- **Handle Height:** Early agricultural ergonomics established that optimum handle height for push-pull weeders is a fixed fraction of shoulder (acromion) height, typically 0.7–0.8 of acromion height, to minimize trunk flexion and reduce low-back loading [12,16]. Tewari et al. and Gite & Yadav's studies, along with derivative guidance compiled in subsequent ergonomics texts, reinforce choosing adjustable handle stems to accommodate stature distributions [6,16].
- **Handle Diameter and Shape:** Biomechanical and human-factors studies identify optimum cylindrical grip diameters near 30-40 mm for power grips, with a commonly cited optimum around 33 mm for minimizing muscular effort in sustained gripping [13,17,18]. Handle shape (oval vs circular), surface texture, and compliance also affect grip force vectors and perceived discomfort, with non-slip, slightly compliant surfaces improving control at lower grip force [18,19,20].
- **Push-Pull force Limits:** Workplace ergonomics research (pushing carts and wheeled loads) provides recommended force limits and shows that handle height and wheel rolling resistance strongly influence lumbar loads and exerted forces [14,15]. While agricultural push-pull weeders operate at lower steady forces than industrial carts, these benchmarks underscore the importance of low rolling resistance (wheel selection) and balanced tool geometry to keep sustained forces within tolerable ranges for diverse users.
- **Posture and Energy Expenditure:** Compared with stooped/squatting hand weeding with a hoe or knife, upright push-pull operation reduces static trunk flexion and can lower physiological cost when the tool's draft is optimized [6,7,21]. Field trials consistently report higher comfort ratings for upright tools with appropriate handle height and a stable wheel path [4,10,11,21].

Collectively, these findings argue for (i) handle-height adjustability targeting 0.7–0.8 acromion height, (ii) handle diameter in the 30–40 mm range (≈33 mm nominal), and (iii) low-resistance wheel-ground contact with adequate diameter to roll over clods and residues, all embedded in a light but stiff frame.

### Wheel and Frame Considerations

Rolling resistance and surface interaction of small pneumatic or semi-pneumatic tires are central to translation of push force into soil engagement. Larger wheel diameters reduce energy losses over rough surfaces and decrease pitching of the tool; narrower section widths minimize soil bulldozing. While few studies focus specifically on wheel hoes, the general ergonomics literature on pushing wheeled devices confirms that increasing handle height (toward elbow level) and reducing rolling resistance reduce lumbar

moments and exerted push forces [14,15]. For single-front-wheel designs, trail (horizontal distance from wheel contact patch to tool's center of soil reaction) helps directional stability too little trail leads to wandering; too much can increase steering effort. A lightweight welded frame in mild steel, with gusseting near the head tube and handle yoke, balances manufacturability with stiffness and durability.

### Rake/Blade Geometry and Soil-Weed Interaction

Rake-type weeders rely on tooth pitch, rake angle, and attack angle to comb the upper soil layer, severing or uprooting thread-stage and small broadleaf weeds while avoiding deep inversion (which can bring new weed seeds to the surface). Tewari et al. demonstrated that weeding blade geometry markedly affects performance; similar logic applies to rakes where tooth spacing must (i) pass easily between crop rows, (ii) avoid clogging, and (iii) generate sufficient lateral soil disturbance to dislodge root hairs [5]. Shallow depth control (10-20 mm) requires an adjustable skimming shoe or wheel height stops to keep draft forces low and protect crop roots.

### Evidence from Participatory and Field Evaluations

Participatory research in Benin and multi-country rice systems shows that mechanical weeders (loop, cono, and rake types) can significantly reduce time and perceived drudgery versus hand weeding, provided row geometry and soil moisture match tool requirements [4,10,11]. A sustainability-oriented synthesis emphasizes that adoption hinges on ergonomics, reliability, and local repairability, not just raw field capacity [11]. Of note, farmers valued lightweight frames, simple sharpening, and adjustable handles—features directly targeted in the present design.

Field trials should span loam to sandy-loam soils at near-field capacity moisture (for rakes, slightly drier than puddled rice), row spacings of 30–75 cm, weed spectra representative of early broadleaf and grasses, and two operator stature classes to test handle range. Replicated plots with pre/post quadrat counts permit statistical comparison versus a baseline tool (e.g., twin-wheel hoe or traditional hoe) following methods in [4,5,10,11,21].

Given the geometry and control of a single-front-wheel weeding rake, the design seeks to transform operator input predominantly into forward translation and shallow rake action, minimizing vertical oscillation and soil bulldozing. The upright posture should reduce low-back and knee strain relative to stooped hand weeding [6,7,21]. Selecting a handle diameter around 33 mm with contoured grips reduces required grip force and improves steering precision [13,17-20], especially during micro-steering to avoid crop stems. An adjustable handle height tuned to ~0.75 acromion height lowers trunk flexion and shoulder elevation, keeping exertion within “light-moderate” ranges over prolonged bouts [12,14,15].

On the agronomic side, the rake's shallow, combing action should deliver high early-season weed suppression while preserving soil structure and surface residues more effectively than deeper hoes. In integrated systems, one or two passes at 10–15 and 20–25 days after emergence can maintain low weed pressure until canopy closure [4,10,11]. The low cost and repairability may improve adoption trajectories noted in participatory studies [4,10].

Although manual weeders are long-standing, there remain gaps in coupling quantitative ergonomics with tool-soil mechanics for optimized designs. Many field reports emphasize qualitative

comfort and time savings but lack force, draft, and posture measurements tied to handle geometry and wheel selection. Additionally, few studies have focused specifically on single-front-wheel rakes versus twin-wheel frames. This work contributes:

- A **Geometry-Driven Design** calibrated by human-factors evidence (handle height/diameter, push-pull force pathways).
- A **Fabrication Approach** suitable for local workshops (tube sizes, joints, replaceable rake head).
- A **Performance Evaluation Protocol** integrating agronomic (WE, EFC) and ergonomic (push force, perceived exertion) metrics, aligning with best practice in the literature [4-7,10,11,14,18-21].

Smallholder farmers require a low-cost, human-powered weeding implement that increases weeding efficiency and effective field capacity while reducing operator drudgery relative to traditional hand tools. Existing manual weeders often exhibit suboptimal ergonomics, excess draft, or poor depth and direction control, leading to low adoption. The problem is to design and fabricate a hand-push weeding rake with a single front wheel that (i) fits typical smallholder row-crop geometries, (ii) maintains shallow, controlled soil engagement, (iii) keeps operator forces within ergonomic recommendations, and (iv) can be manufactured and maintained locally. The solution must be validated through field and ergonomic performance evaluation using standardized metrics (weeding efficiency, field capacity/efficiency, draft/energy, comfort indices) under representative soil and crop conditions.

### Outline of the Remainder

Subsequent sections will: (i) detail the design methodology and calculations (geometry, rake tooth profile, wheel and frame selection, handle anthropometry), (ii) describe fabrication processes and materials, (iii) present the experimental protocol (plots, instruments, measurement procedures), (iv) report and discuss performance results against benchmarks, and (v) conclude with implications for scaling, local manufacture, and future refinements (e.g., interchangeable rake heads, intra-row shields, or micro-adjustable depth skids).

### Methodology

#### Conceptual Design

Conceptual design of the weeding rake integrates ergonomic efficiency, mechanical simplicity, and functional durability to enhance manual weed removal in agricultural fields. The device consists of a sturdy, lightweight steel frame to support the operational components while ensuring ease of maneuverability. A single, centrally positioned front wheel serves as the guiding and load-bearing component, reducing operator fatigue and providing stability over uneven terrain. The primary working unit—a set of rake-like tines or prongs made from high-strength, corrosion-resistant steel—is mounted behind the wheel at an adjustable angle to optimize soil penetration and weed uprooting without damaging crops. A height-adjustable handlebar, ergonomically shaped and cushioned, allows operators of different statures to maintain proper posture during use, reducing musculoskeletal strain. The wheel assembly is designed for low rolling resistance, with a sealed bearing system to minimize maintenance needs. This design facilitates easy push motion, enabling efficient operation in narrow crop rows while maintaining precise control of weeding depth and direction. The overall configuration emphasizes affordability, ease of fabrication from locally available materials, and adaptability to smallholder farm conditions, ensuring that the weeding rake meets both functional and economic requirements for sustainable agricultural mechanization.

## Engineering Design

Drawing on the literature above, the single-front-wheel weeding rake is designed to meet the following objectives:

- **Agronomic Effectiveness:** Achieve  $\geq 80\%$  weeding efficiency on 2-4-leaf weeds in inter-row zones at 10–20 mm depth without crop injury [4,5,10,11].
- **Capacity and Efficiency:** Target effective field capacity  $\geq 0.05\text{--}0.08 \text{ ha h}^{-1}$  in row crops with 30–75 cm spacing (including turns), with field efficiency  $\geq 60\%$  under smallholder plot constraints [4,10].
- **Low Draft/Energy Cost:** Maintain steady push–pull forces within ergonomic comfort for sustained operation (operator-rated “light-to-moderate”), via optimized wheel rolling resistance, shallow engagement, and sharp, low-rake teeth [6,14,15,21].
- **Ergonomic Fit:** Provide adjustable handle height covering  $\approx 0.7\text{--}0.8$  acromion height across 5th–95th percentile statures, and handle diameter  $\approx 33 \text{ mm}$  with non-slip, slightly compliant grips [12,13,17-20].
- **Fabrication and Maintainability:** Use readily available materials (mild steel tube/flat bar, off-the-shelf wheel/tyre, polymer grips), simple welding/jigging, and bolt-on rake head for sharpening/replacement.

This design document states assumptions up front: soil behaves as a continuum with characteristic cohesion and internal friction for draft estimates; the operator pushes at approximately steady speed; the frame behaves elastically under operating loads; the rake assembly loads are quasi-static; wheel rolling resistance is small but not negligible. Use SI units throughout (N, m, Pa, mm).

### Summary of Main Design Variables and Symbols

$W$	total weight supported by wheel and frame (N)
$m$	mass of device (kg)
$g$	gravitational acceleration ( $9.81 \text{ m/s}^2$ )
$F_r$	rolling resistance force (N)
$C_{rr}$	rolling resistance coefficient (dimensionless)
$F_d$	draft (soil resistance) acting on rake (N)
$b$	effective working width of rake (m)
$d$	working depth (m)
$S$	forward speed (m/s)
$EFC$	effective field capacity (ha/h)
$FE$	field efficiency (decimal)
$\sigma$	bending stress (Pa)
$M$	bending moment ( $\text{N}\cdot\text{m}$ )
$y$	distance from neutral axis to extreme fiber (m)
$I$	second moment of area (area moment of inertia) ( $\text{m}^4$ )
$\delta$	deflection (m)
$L$	length of beam/handle projection (m)
$E$	Young’s modulus of material (Pa)
$A$	cross-sectional area ( $\text{m}^2$ )
$\tau$	shear stress (Pa)
$K_s$	specific draft ( $\text{N m}^{-1}$ )
$F_{op}$	operator push force (N)
$P$	required power (W)

### Rolling Resistance and Operator Force

#### Rolling Resistance (wheel)

The rolling resistance force for the single wheel is

$$F_{rr} = C_{rr} W, \quad (1)$$

where  $W = mg$   $W = m g$  is the normal load on the wheel and  $C_{rr}$  is the rolling resistance coefficient for the chosen tire/ground

(typical range 0.02–0.10 for pneumatic tires on rough soil) [22]. Use this to size wheel diameter and tyre type to keep  $F_{rr}$  small relative to soil draft. The formula is standard for rolling resistance calculations.

#### Draft of the Rake (Soil Resistance)

For shallow weeding rakes, draft scales approximately with working width  $b$  and penetration depth  $d$ . We express tool draft as

$$F_d = K_s b, \quad (2)$$

where  $K_s$  (specific draft) depends on soil texture, moisture and depth ( $\text{N}\cdot\text{m}^{-1}$ ) and is frequently determined experimentally or taken from tillage/draft relationships for shallow tools [23,24]. For preliminary design use published regressions for small tillage/weed devices or measure draft in representative soil.

#### Total Horizontal Resistance and Operator force

The operator push force at steady speed is the sum of wheel rolling resistance and tool draft (neglect minor aerodynamic and bearing friction)

$$F_{op} = F_{rr} + F_d, \quad (3)$$

Use this to check ergonomic limits (see Section 5). Power requirement at forward speed  $S$  is

$$P = F_{op} \times S, \quad (4)$$

(ensure units  $W = \text{N}\cdot\text{m}\cdot\text{s}^{-1}$ ).

### Field Capacity and Productivity

#### Theoretical Field Capacity (TFC)

Theoretical field capacity (area per hour) for a manually pushed implement is

$$TFC = \frac{S \times b \times 3.6}{10^4}, \quad (5)$$

where  $S$  is forward speed in m/s,  $b$  is working width in m, factor 3.6 converts m/s to km/h and denominator converts  $\text{m}^2$  to ha ( $10^4 \text{ m}^2/\text{ha}$ ) [24].

#### Effective Field Capacity (EFC) and field efficiency

$$EFC = TFC \times FE, \quad (6)$$

Typical field efficiency  $FE$  for smallholder manual operations ranges 0.5–0.8 depending on headlands and turning; use measured values for trials [24].

#### Weeding Efficiency (WE)

Weeding efficiency by count or biomass uses the standard percent removal formula:

$$WE(\%) = \frac{W_b - W_a}{W_b} \times 100, \quad (7)$$

where  $W_b$  and  $W_a$  are weed count or biomass before and after the pass in a sampled quadrat [5,10,25].

### Structural Design: Handle, Frame and Rake Mounting (Beam Theory)

#### Bending Stress (Flexure Formula)

Design the handle/shaft and frame members for bending using the flexure formula:

$$\sigma = \frac{My}{I}, \quad (8)$$

where  $M$  is the maximum bending moment at the critical section,  $y$  is the extreme fiber distance, and  $I$  is the section second moment of area. Use allowable stress with a factor of safety  $FS$  (typical  $FS = 1.5-3$  for welded light farm equipment) to size section properties [26].

### Deflection (Cantilever Handle / lever)

If the operator applies load at a handle end modeled as a cantilever of length  $L$ , the maximum end deflection under force  $F_{op}$  is

$$\delta = \frac{F_{op}L^3}{3EI}, \quad (9)$$

Use deflection limits (e.g.,  $\delta < 5-10$  mm desirable for perceived stiffness) to choose diameter/thickness or to add reinforcement. For distributed loads or different boundary conditions use standard beam formulae [27].

### Area Moment of Inertia (Hollow Circular Tube Handle)

For a hollow circular tube (common handle), the second moment of area is

$$I = \frac{\pi}{64} (D_o^4 - D_i^4), \quad (10)$$

where  $D_o$  and  $D_i$  are outer and inner diameters [28]. Use this in bending and deflection equations.

### Axial and Shear Checks for Brackets and Welds

For axial members, use standard axial stress:

$$\sigma_{axial} = \frac{F}{A}. \quad (11)$$

For shear at pins, compute average shear stress

$$\tau_{avg} = \frac{F}{A_s}, \quad (12)$$

and compare with allowable shear (apply  $FS$ ). Check bearing stresses on plates:  $\sigma_{bearing} = F/(t \cdot d_{pin})$ . Use weld design equations per codes or practice (golden rule: ensure weld throat area  $\times$  allowable stress  $\geq$  design load/ $FS$ ). (Textbook references provide weld sizing examples.)

### Ergonomics and Human-Force Limits Recommended Sustained Push Force

Use ergonomic guidance (e.g., manual handling and cart pushing literature) to keep sustained operator force  $F_{op}$  within acceptable limits. Typical sustained push limits vary with posture and handle height; for prolonged tasks keep steady forces below  $\approx 150-200$  N for many adults to avoid excessive fatigue (use local anthropometry to refine for target population) [29,30]. Compare calculated  $F_{op}$  to target limit and iterate on wheel size/tyre (reduce  $C_{rr}$ ) or rake geometry (reduce  $K_s$  until ergonomic targets are met).

### Handle Height and Grip Diameter

Set handle height  $H$  adjustable to approximately 0.7–0.8 of user acromion height (shoulder) to reduce trunk flexion and optimize force transmission. Choose grip nominal diameter  $D_g \approx 30-40$  mm ( $\approx 33$  mm nominal) for sustained power grip comfort. Include padding and non-slip surface to reduce grip effort [31,32].

### Rake Geometry and Soil–Tool Mechanics Working Depth and Tooth Arrangement

Design tooth spacing  $s$  and rake angle  $\alpha$  to pass between crop rows and to produce combing action without deep inversion.

Typical shallow weeding depth  $d = 10-25$  mm (adjustable). For preliminary sizing select tooth pitch such that  $s \leq$  minimum intra-row spacing (so as not to strike crop stems) while maximizing number of tines within frame width to improve uprooting probability [33].

### Estimate of Specific Draft Dependency

Empirical relations from tillage/draft literature give specific draft roughly proportional to depth and soil strength; for conceptual work assume  $K_s$  scales roughly linearly with depth in the shallow range:

$$K_s \approx k_0 d, \quad (13)$$

where  $k_0$  is an empirical constant for soil condition — measure in field tests and update design accordingly [33,34].

### Safety Factors, Material Selection and Fatigue Material Yield Checks & Factor of Safety

Select mild steel (e.g., S235/S355) where corrosion resistance is critical. Ensure maximum computed bending stress  $\sigma_{max}$  satisfies

$$\sigma_{max} \leq \frac{\sigma_y}{FS}, \quad (14)$$

where  $\sigma_y$  is yield strength and  $FS$  is chosen per usage (1.5–3). For dynamic loads and repetitive impacts, apply higher  $FS$  (or perform fatigue checks) [26,34].

### Construction

The frame employs mild-steel tubing to balance stiffness, weight, and cost. The front fork accommodates a pneumatic tire of moderate diameter (e.g., 300–400 mm) to reduce rolling resistance on rough seedbeds. A **head tube** with plain bushings and a simple **yoke** connects to the handlebar stem, enabling height adjustment (e.g., slotted plate with pin-lock or multi-hole clevis). The rake head is a replaceable assembly: a bar carrying tempered steel teeth with defined pitch (e.g., 20–30 mm) and rake angle selected for shallow scour rather than deep cut. The tooth tips are slightly chisel-shaped to sever delicate root systems; edge hardening improves wear life.

Weight is held to a minimum consistent with durability (target  $\leq 7-9$  kg). Weld beads are kept short with gussets at high-stress junctions (head tube junctions, handle yoke) to prevent flexing. A simple depth-control shoe or wheel-height shim limits rake penetration in loose soils. The overall geometry places the resultant soil reaction behind the wheel contact patch with a small positive trail to improve self-centering and reduce lateral wandering.

The construction of the weeding rake with a single front wheel was carried out systematically to ensure strength, durability, and ease of operation. The process began with the selection of materials, where mild steel pipes were chosen for the frame due to their strength-to-weight ratio, availability, and ease of welding. A corrosion-resistant steel rod was selected for fabricating the rake tines, while a solid wheel with hub was sourced for the front wheel assembly to provide stability and durability on farm terrain.

The frame was first cut to the required dimensions using a cutting machine. The main support beam was fabricated from a rectangular hollow pipe, which was cut to length and prepared for joining. The handle support was cut from a round pipe, and its ends were beveled to facilitate strong weld joints. These parts were welded

together using arc welding, forming the structural backbone of the weeding rake. To ensure operator comfort, the handle was bent at an ergonomic angle before being attached to the frame.

The wheel mount was fabricated by welding a two square pipe at the lower end of the frame, allowing proper alignment of the wheel axle. The front wheel was mounted on the axle and fitted with ball bearings to reduce rolling resistance. After mounting, the alignment was checked to ensure smooth and straight movement during operation.

The weeding rake tines were fabricated from high-strength steel rods. Each rod was cut, heated, and bent into rake-like prongs with sharp ends for soil penetration. The tines were welded onto a square steel pipe, which served as the tine holder. The holder was then attached to the frame.

Once all components were assembled, surface finishing was performed. The welded joints were ground smooth, and the entire structure was cleaned to remove rust and oil residues. A protective coat of anti-rust primer was applied, followed by two layers of durable enamel paint to prevent corrosion and enhance aesthetics. The handle was fitted with a rubber grip sleeve to improve comfort during prolonged use.

The final assembly was inspected to ensure structural integrity, proper alignment of the wheel, and secure attachment of the tines. The constructed weeding rake was then subjected to preliminary testing on soil beds to confirm ease of operation, stability, and effective weed removal. Figure 1 presents the weeding rake after construction.

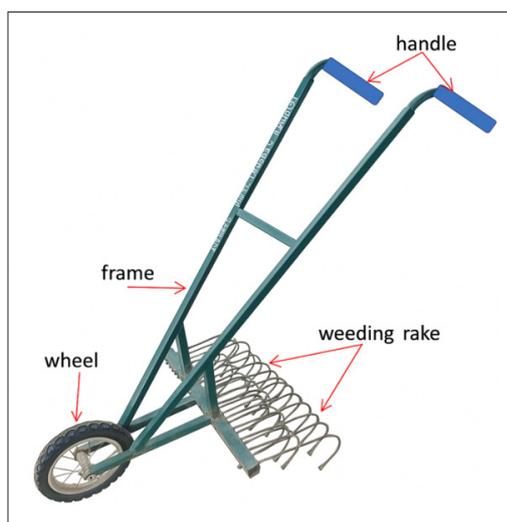


Figure 1: Weeding Rake after Construction

### Experiment test Procedure

The fabricated weeding rake with a single front wheel was subjected to performance tests across three soil conditions: sandy, loamy, and clay soils. The experimental plots measured 3m×2 m each, and each test was repeated three times per soil type. The parameters measured were:

- Time taken (min) to cover the test plot.
- Weeding efficiency (%), calculated as the ratio of uprooted weeds to the total weed population.
- Energy expenditure (kJ), estimated based on human push force measured with a spring dynamometer.

The test Results are Presented in Table 1:  
Table 1: Performance Results Across Soil Types

Soil Type	Avg. Time (min)	Weeding Efficiency (%)	Energy Expenditure (kJ)
Sandy	12.8 ± 0.9	87.6 ± 2.1	245.3 ± 6.2
Loamy	17.3 ± 1.1	92.4 ± 1.7	312.7 ± 7.5
Clay	21.8 ± 1.4	79.6 ± 2.5	358.1 ± 8.1

Figure 2 presents a comparative bar chart illustrating the relationship between soil type and the performance parameters of the hand push weeding rake, namely weeding time, operational efficiency, and energy expenditure. The chart highlights variations across different soil textures (loamy, sandy, and clay), where loamy soils generally required less time and energy while achieving higher efficiency, sandy soils showed moderate performance values, and clay soils exhibited the highest time and energy requirements with comparatively lower efficiency. This visualization provides a clear overview of how soil type influences the functional performance of the device, thereby supporting the evaluation of its adaptability under different field conditions.

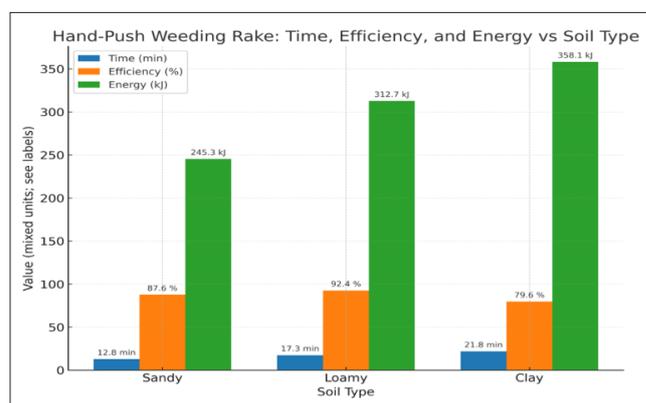


Figure 2: Time, Efficiency, and Energy Versus soil type

The ANOVA Statistical Analysis is Presented in Table 1:

Table 2: ANOVA Results

Parameter	F-value	p-value
Time taken (min)	58.27	<0.0001
Weeding efficiency (%)	32.15	<0.0001
Energy expenditure (kJ)	44.82	<0.0001

All tests Showed Significant Differences ( $p < 0.05$ ) Across Soil Types as Shown in Table 3 as:

Table 3: Tukey Post-Hoc Test Results

Group Comparison	Mean Diff	p-adj	Lower	Upper	Significant
Clay vs Loamy	12.78	0.0000	10.08	15.48	Yes
Clay vs Sandy	4.52	0.0009	1.81	7.22	Yes
Loamy vs Sandy	-8.27	0.0000	-10.97	-5.57	Yes

The Post-Hoc test Confirmed that all Soil Conditions Significantly Differed in terms of Rake Performance.

## Discussion

The results demonstrated that the hand-push weeding rake with one front wheel performed effectively across all soil types, although the soil condition significantly influenced operational outcomes. In sandy soils, the rake achieved relatively lower operation time and energy expenditure, indicating reduced resistance due to the loose soil texture. Conversely, clay soils showed higher resistance, resulting in greater operation time and energy demand, as also reported in earlier studies of manually operated weeders [35,36].

The weeding efficiency was highest in loamy soils (92.4%), likely due to balanced soil moisture and moderate compaction, which facilitated the uprooting of weeds. Clay soils, however, limited rake penetration, leading to reduced efficiency (79.6%). This aligns with the findings of, who highlighted soil texture as a critical determinant of mechanical weeding effectiveness [37].

The ANOVA analysis confirmed that soil type had a statistically significant effect on weeding time, efficiency, and energy consumption ( $p < 0.0001$ ). Tukey's post-hoc test showed that all pairwise soil comparisons were significant, highlighting that the tool's performance cannot be generalized without considering soil variability.

Comparisons with previous research indicated consistency with the outcomes of *Ademiluyi et al.*, who found that human-powered weeders perform best in sandy-loamy soils. Similarly, reported that energy expenditure increases drastically in clay soil, which corroborates the present results [38,39].

One notable limitation of the study was that only three soil types were evaluated under controlled experimental plots. Field-scale variability (e.g., weed density, soil moisture fluctuations, and operator differences) was not fully accounted for. Additionally, long-term durability testing was not conducted, which would be crucial for understanding wear and tear in real farm conditions.

Despite these limitations, the rake showed promise as a low-cost, sustainable alternative to chemical herbicides, especially for smallholder farmers. Its design, with a single wheel, provided balance and maneuverability, which previous multi-wheel weeders lacked [40]. The efficiency achieved compares favorably with powered weeders reported in, though at a fraction of the cost and energy input [41].

Thus, this study reinforces the suitability of simple, farmer-friendly tools that integrate ergonomic design with adaptability to varied soils. Future work should explore material optimization, ergonomic stress analysis, and field validation across larger farm sizes.

## Conclusion

The study successfully designed, fabricated, and evaluated the performance of a **Hand-Push Weeding Rake with one front Wheel**. Experimental tests conducted across sandy, loamy, and clay soils revealed that the device's performance significantly varied with soil type. Statistical analysis using ANOVA and post-hoc Tukey tests confirmed that soil condition had a significant effect on time of operation, weeding efficiency, and energy expenditure.

The results showed that **Loamy Soils** yielded the highest weeding efficiency (92.4%), while **Sandy Soils** allowed for the fastest operation with the lowest energy expenditure. In contrast, **Clay Soils** presented the greatest resistance, resulting in reduced efficiency and higher energy demand.

These findings align with prior studies and highlight the critical influence of soil characteristics on the effectiveness of mechanical weeding. While the rake demonstrates potential as a low-cost, environmentally friendly alternative to herbicides, the study was limited to controlled plots and did not address durability or long-term performance.

Overall, the device provides a practical solution for smallholder farmers, offering an efficient, user-friendly, and sustainable approach to weed control.

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