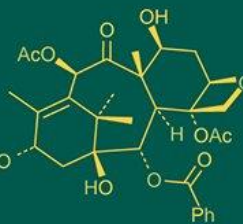
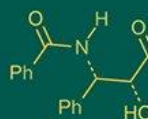


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Anusha S
Department of Farm
Machinery and Power
Engineering, College of
Agricultural Engineering, UAS
Raichur, Karnataka, India

Sunil Shirwal
Department of Farm
Machinery and Power
Engineering, College of
Agricultural Engineering, UAS
Raichur, Karnataka, India

Bhagyashree
Department of Farm
Machinery and Power
Engineering, College of
Agricultural Engineering, UAS
Raichur, Karnataka, India

Raviraj J
Department of Farm
Machinery and Power
Engineering, College of
Agricultural Engineering, UAS
Raichur, Karnataka, India

Murali M
Department of Farm
Machinery and Power
Engineering, College of
Agricultural Engineering, UAS
Raichur, Karnataka, India

Satish
Department of Farm
Machinery and Power
Engineering, College of
Agricultural Engineering, UAS
Raichur, Karnataka, India

Corresponding Author:
Anusha S
Department of Farm
Machinery and Power
Engineering, College of
Agricultural Engineering, UAS
Raichur, Karnataka, India

Ergonomic assessment and design consideration of manual weeders for Indian agricultural workers

Anusha S, Sunil Shirwal, Bhagyashree, Raviraj J, Murali M and Satish

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Abstract

Manual weeding is a critical agricultural operation that significantly influences crop productivity, particularly in smallholder farming systems. However, traditional weeding practices are often labour-intensive and associated with high levels of drudgery, leading to musculoskeletal disorders and reduced work efficiency among farm workers. This review paper aims to analyse the design, performance, and ergonomic aspects of manual weeders to identify improvements that enhance operator comfort and productivity. The study is based on a systematic review of peer-reviewed articles, technical reports, and agricultural research publications. Key aspects such as weeding efficiency, field capacity, energy expenditure, posture, and tool design parameters were evaluated. Various ergonomic assessment methods, including subjective techniques (RPE, VAS), observational tools (RULA, REBA, OWAS), and physiological measurements (heart rate and energy expenditure), were examined to assess workload and operator strain. The findings indicate that ergonomically designed weeders, such as improved wheel hoes and long-handle tools, significantly reduce physical strain by enabling standing posture and minimizing bending and squatting. Proper design considerations, including handle geometry, tool weight, and blade configuration, play a crucial role in improving efficiency and reducing fatigue. Additionally, advancements in ergonomic evaluation techniques and emerging technologies offer new opportunities for optimizing agricultural tool design.

Overall, the review highlights the importance of integrating ergonomic principles into weeder design to reduce drudgery, improve work efficiency, and enhance the well-being of agricultural workers. The insights provided can support the development of user-friendly and efficient weeding tools suitable for diverse farming conditions.

Keywords: Manual weeder, Ergonomic evaluation, Agricultural tools, Drudgery reduction, RULA, REBA, Work efficiency, Tool design

1. Introduction

Agriculture is a major sector of India's economy, employing about 54.6% of the population and contributing significantly to food security and raw material supply. Among various agricultural operations, weeding is essential for maintaining crop productivity as weeds compete with crops for nutrients, water, light, and space. In India, where small and fragmented land holdings dominate, manual weeding using traditional tools such as khurpi, hoes, sickles, and spades is still widely practiced. However, these operations are labour-intensive and are often performed in ergonomically unsuitable postures, leading to fatigue, physical strain, and musculoskeletal disorders among workers.

Weeding accounts for nearly 25% of the total labour requirement (900-1200 man-hours ha⁻¹) during a cultivation season (Nag & Dutta, 1979) [35]. Hand weeding alone may require 400-600 man-hours ha⁻¹, depending on weed infestation. Delay in weeding operations can reduce crop yield by 30-60% (Singh, 1988). In India, about ₹4.2 billion is spent annually on weed control and approximately 40 million tonnes of food grains are lost each year due to weeds (Singh & Sahay, 2001). Yield reductions ranging from 5-60% have been reported due to weed competition, with several problematic weeds such as *Cyperus rotundus*, *Cynodon dactylon*, *Phalaris minor*, and *Parthenium hysterophorus* infesting large areas of the country (Biswas *et al.*, 1999).

Although several improved manual weeders such as wheel hoes and triangular blade hoes have been developed, their adoption remains limited due to factors such as tool weight, lack of awareness, and incompatibility with small farms (Kumar, 1983). Mechanical weed control

helps remove weeds between rows while improving soil aeration and water infiltration (Biswas, 1990). Studies have also shown that ergonomically designed weeders can significantly reduce workload and fatigue. For example, a wheel hoe developed with ergonomic considerations required 60-110 man-hours ha⁻¹ in heavy soil and about 25 man-hours ha⁻¹ in light soil (Singh, 1992). Further ergonomic evaluations indicated that a push-pull force of about 60 N during weeder operation resulted in minimum fatigue and better human-machine interaction (Kumar *et al.*, 2000).

The need for ergonomically optimized manually operated weeders is therefore evident. Modifications such as adjustable handle angles (45-65°), lightweight frames, and optimized cutter blades have been introduced to reduce physiological stress and body discomfort during operation. Ergonomics, defined as the science of designing work systems and tools to suit human capabilities (Pheasant, 1991) [42], plays an important role in improving agricultural tool efficiency and safety. The adoption of ergonomic principles in the design and testing of farm tools has also been recommended by FAO (1994). Considering the shortage of agricultural labour (Raut *et al.*, 2013) [43] and the importance of effective human-machine interaction (Singh *et al.*, 2019a), ergonomically improved manual weeders can help reduce drudgery, enhance operator comfort, and improve overall productivity in smallholder farming systems.

As such, this review paper aims to provide a comprehensive overview of the current status of weed management systems in India. Weeding is a crucial agricultural operation but remains highly labour-intensive, time-consuming, and physically demanding, especially in smallholder farming systems. Traditional hand tools often cause operator fatigue, discomfort, and reduced efficiency due to poor ergonomic design. Ergonomically improved manually operated weeders can significantly reduce drudgery, physiological stress, and labour requirements while improving work efficiency. Therefore, incorporating ergonomic principles in the design and modification of weeding tools is essential to enhance operator comfort, productivity, and overall agricultural sustainability.

2. Scope And Structure

This section begins with an overview of manual weed control equipment and highlights the importance of effective weeding management in agriculture. It discusses the current practices followed in manual weeding and the major challenges associated with labour intensity, time consumption, and operator discomfort. Further, the classification of manual weeders based on their design and mode of operation is presented.

Next, the ergonomic principles involved in agricultural tool design are explained, focusing on aspects such as gender considerations, power requirements, and working positions of operators. The section also describes the methods used for ergonomic evaluation of manual weeding tools, including physiological and postural parameters. Finally, a comparative analysis of ergonomically developed manual weeders is presented to understand their efficiency, operator comfort, and suitability for agricultural operations.

3. Current status and challenges in India

Manual weeding is still widely practiced in India, especially by small and marginal farmers, using traditional tools such as khurpi, hoes, and spades due to small and fragmented land holdings. However, this method is highly labour-

intensive and accounts for nearly 25% of the total labour requirement in crop production (Nag and Dutta, 1979) [35]. Although improved manually operated weeders have been developed, their adoption remains limited due to lack of awareness, limited availability in local markets, and higher initial cost. Labour shortages and increasing wage rates further increase the difficulty of timely weeding operations. In addition, many existing tools lack proper ergonomic design and are not suitable for female workers, who constitute a large portion of the agricultural workforce. These constraints highlight the need for ergonomically designed, affordable, and easily accessible manual weeders to improve efficiency and reduce drudgery.

4. Methodology

This review synthesises peer-reviewed journal articles, conference papers, government reports, and technical publications related to manual weeders and ergonomic assessment in agriculture published between 1990 and 2025. Relevant literature was collected from databases such as Google Scholar, ScienceDirect, SpringerLink, and Indian agricultural research repositories (ICAR and CIAE). A total of more than 60 publications were reviewed, with particular emphasis on studies conducted under Indian farming conditions and smallholder systems. Selected studies focused on design improvements, ergonomic interventions, and performance evaluation of traditional and improved weeders. Data extraction was carried out based on parameters such as weeding efficiency, field capacity, heart rate, energy expenditure, postural stress, and tool design characteristics. Both qualitative and quantitative findings were analysed to evaluate the relationship between tool design, operator comfort, and work efficiency.

The review also incorporates different ergonomic evaluation methods, including subjective assessment (RPE, VAS), observational techniques (RULA, REBA, OWAS), and physiological measurements (heart rate and energy expenditure), to provide a comprehensive understanding of workload and drudgery in manual weeding operations.

5. Overview of manual weed control equipment

Weed management is essential for maintaining crop productivity and ensuring food security, as weeds compete with crops for light, water, nutrients, and space, and may also harbor pests and diseases. If not controlled, weeds can cause severe yield losses, sometimes up to 100% depending on crop type and weed density (Oerke, 2006). In India, average yield losses due to weeds have been reported as 36% in peanut, 31% in soybean, 25% in maize, and 19% in wheat, highlighting the importance of effective weed management strategies (Gharde *et al.*, 2018).

Weed control methods include manual, mechanical, chemical, cultural, and integrated approaches. Manual weeding using simple hand tools such as hoes and sickles is still widely practiced in smallholder farming systems. Mechanical weeders and power-operated tools are gradually being adopted to reduce labour dependency, while herbicides are commonly used due to their quick and economical action. However, excessive herbicide use has led to the development of herbicide-resistant weed species worldwide (Heap, 2019). Therefore, Integrated Weed Management (IWM), which combines multiple control methods, is increasingly recommended as a sustainable approach (Chauhan *et al.*, 2017).

Despite its effectiveness, manual weeding is labour-intensive, time-consuming, and accounts for about 25% of

the total labour requirement in crop production (Nag and Dutta, 1979) ^[35]. Labour shortages, rising wages, and migration of rural workers further limit its feasibility. In addition, the use of traditional tools and prolonged bending postures can cause physical strain, fatigue, and musculoskeletal disorders among workers (Singh, 1988). Delayed weeding due to these constraints may reduce crop yield by 30-60%, emphasizing the need for improved

ergonomic tools and efficient weed management practices.

Classification of Manual Weeder

Manual weeding refers to the removal of weeds by human effort using hands or simple hand-operated tools. It is widely practiced in smallholder farming systems, especially in developing countries. Manual weeding can be classified based on the method used, based on power source, type of tool, and mode of operation.

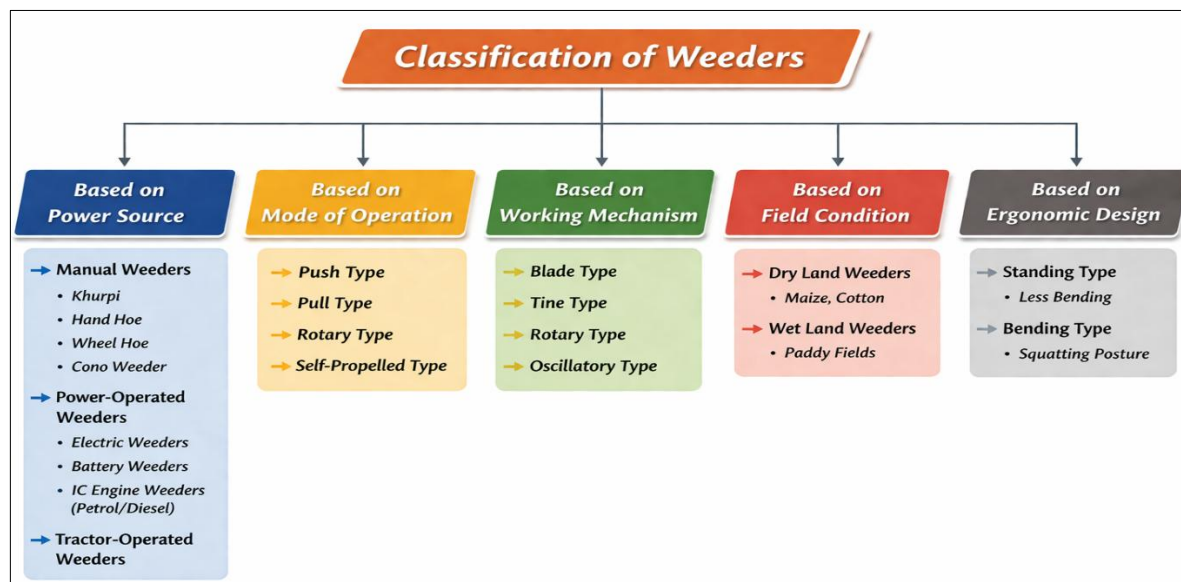


Fig 1: Classification of Manual Weeder

6. Ergonomic principle in agriculture tool design

6.1 Ergonomic Principles Based on Gender, Power and Working Position in Agricultural Tool Design

Recent research highlights the importance of incorporating gender-specific ergonomic principles in the design of agricultural tools to reduce drudgery and improve work efficiency among women farm workers. Anthropometric compatibility is a key factor, as tools must be designed according to the body dimensions, grip strength, and reach characteristics of the actual users. Studies show that women

generally have smaller hand breadth, shorter reach, and lower upper-body strength than men; therefore, tools designed only using male anthropometric data often become oversized and difficult for women to operate effectively. Research on modified wheel hoes and other manual tools demonstrates that designing equipment based on female anthropometric measurements significantly reduces energy expenditure, improves comfort, and increases productivity during operations such as weeding and transplanting (Sinha, Singh, & Kumar, 2023; Negi, Singh, & Singh, 2025) ^[51, 36].

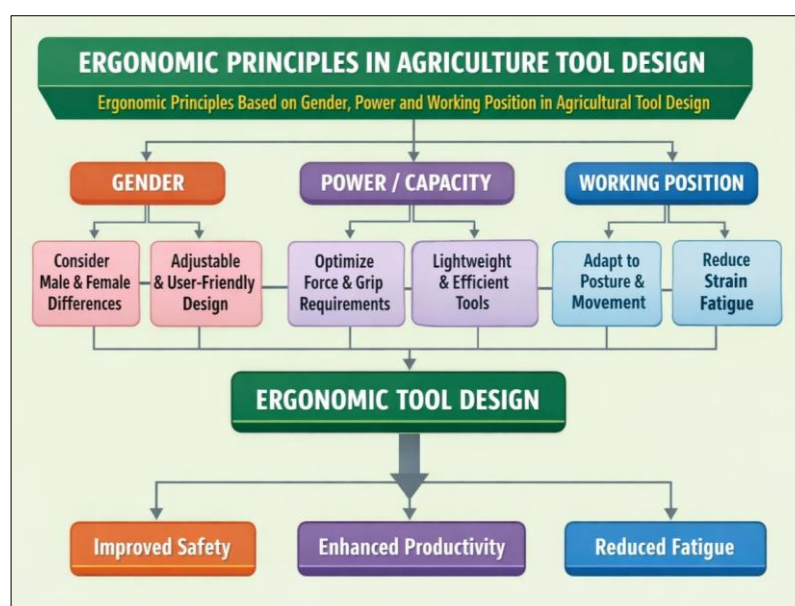


Fig 2: Ergonomic agricultural tool design considers gender, power capacity, and working position to improve safety, productivity, and reduce fatigue

Strength capacity and force requirement are also critical considerations in ergonomic tool design. Agricultural operations such as digging, harvesting, and weeding involve repetitive muscular effort, which can lead to fatigue and musculoskeletal disorders if tools require excessive force. Ergonomic studies indicate that improved agricultural tools designed according to workers' strength capacity reduce physiological workload, including heart rate and energy expenditure, thereby enhancing occupational safety and efficiency (Singh, Jogender, & Rahul, 2022; Mishra,

Bhagat, & Borah, 2024) [32]. Similarly, ergonomic evaluation of manual weeding tools has shown that improved designs can significantly lower cardiac cost of work and reduce drudgery among women farm workers (Anusha, Mehta, & Sharma, 2021). In addition to anthropometric and strength considerations, weight optimization and task-specific design play a major role in ergonomic efficiency. Lightweight tools improve manoeuvrability and reduce strain on the wrists, shoulders, and lower back during repetitive agricultural tasks.

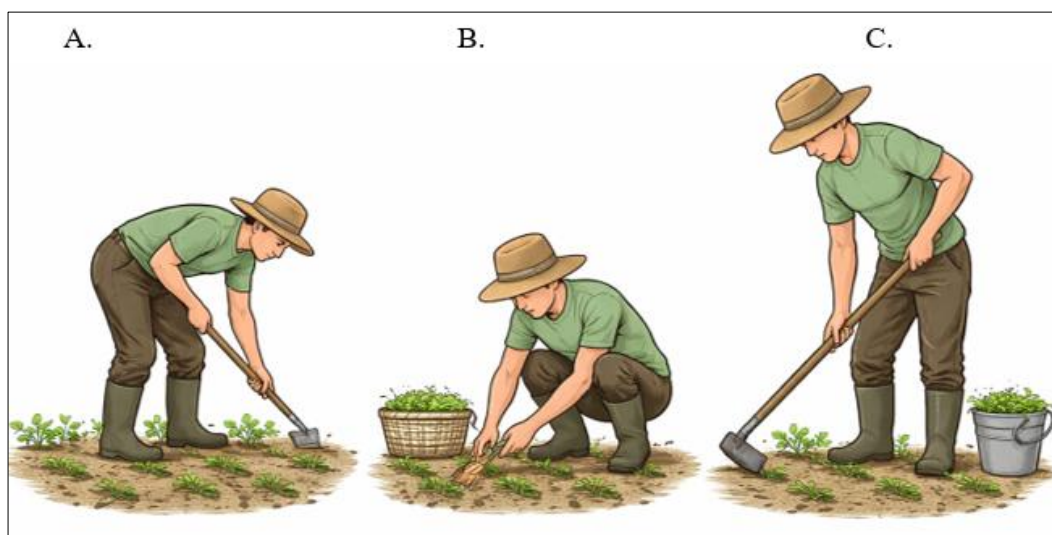


Fig 3: Shows Repetitive motion in agricultural work A. Bending, B. Squatting, C. Standing

Research in rice wheat and millet farming systems indicates that ergonomic interventions and improved tools can significantly reduce physical workload, minimize musculoskeletal problems, and enhance productivity among women farmers (Joshi *et al.*, 2024; Roy Burman *et al.*, 2025) [45]. Therefore, integrating ergonomic principles such

as anthropometric compatibility, reduced force requirement, lightweight design, and task-specific modifications is essential for developing agricultural tools that are safe, efficient, and suitable for women agricultural workers.

6.2 Power-Based Ergonomic Principles

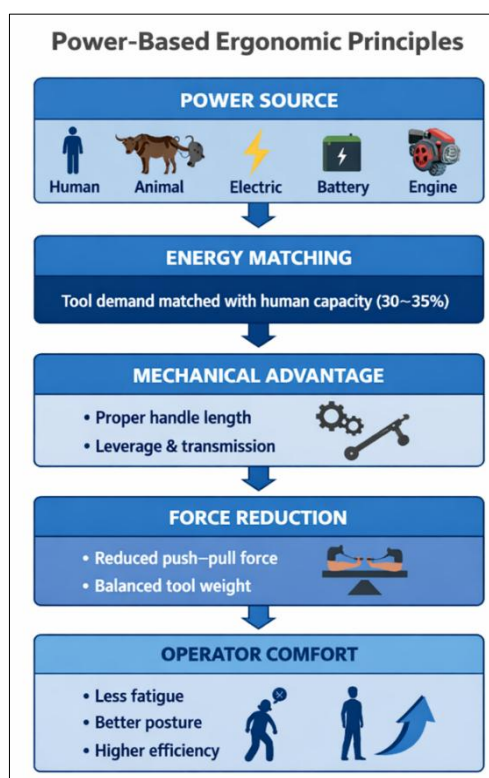


Fig 4: Shows Power -Based Ergonomic Principles

Power-based ergonomic principles emphasize matching the energy requirements of agricultural tools with the physiological capacity of the operator in order to minimize fatigue and improve work efficiency. Agricultural tools may be powered by human effort, animals, electric motors, batteries, or small engines, and the selected power source should ensure that the operator can perform tasks continuously without excessive physical strain. In manually operated agricultural tools, human power limitations are particularly important during the design stage. Ergonomic studies indicate that agricultural workers can sustain only a limited amount of mechanical power during prolonged work, and exceeding this capacity can lead to rapid fatigue and reduced productivity. Research on agricultural workers shows that physiological workload during farm operations should remain within about 35% of maximum aerobic capacity to maintain safe levels of physical strain (Behera, Swain, & Mohanty, 2007) [3].

Mechanical advantage is another essential aspect of ergonomic tool design. Proper leverage systems, optimized handle length, appropriate gear ratios, and efficient power transmission mechanisms help amplify human force and reduce the physical effort required during operations such as digging, cutting, and weeding. Modern agricultural engineering studies demonstrate that ergonomic redesign of manual tools—such as improved handle dimensions and blade configuration—can significantly reduce physiological workload, heart rate, and overall discomfort among farm workers (Sinha, Singh, & Kumar, 2023) [51].

In addition, vibration control, noise reduction, and energy-efficient mechanical systems are critical in power-operated agricultural equipment. Excessive vibration and noise from engines or rotating components can increase operator discomfort and may lead to long-term health problems such as hand-arm vibration syndrome. Recent ergonomic research on agricultural machinery highlights that improved machine balance, vibration-damping materials, and lightweight structural design can significantly reduce physiological stress and improve operator comfort during field operations (Chaudhary *et al.*, 2022) [7].

Reducing static load and evaluating postural risk are also essential in ergonomic tool design. Prolonged bending during tasks such as weeding and harvesting increases spinal stress and fatigue, whereas ergonomic tools like long-handled weeders allow operators to work in a more upright posture and reduce drudgery. Studies indicate that improved tool designs can lower physical workload by 30-40% and enhance productivity (Gite, Agarwal, & Yadav, 2009) [14]. Postural risk in agricultural work is commonly evaluated using ergonomic assessment methods such as RULA, REBA, and OWAS, which analyze body posture, joint angles, and force exertion to identify potential musculoskeletal hazards (Hignett & McAtamney, 2000) [17]. Push and pull forces are another important ergonomic parameter, particularly for push-type tools such as weeders and seeders. Excessive push-pull force increases muscular strain, cardiovascular load, and the risk of low back pain. Ergonomic guidelines suggest that sustained push-pull forces should remain within 20-30% of the operator's maximum voluntary force capacity. Tool design should therefore consider factors such as wheel diameter, weight distribution, handle height, and mechanical advantage to reduce the required force. Considering gender differences in strength capacity is also essential to ensure safe and efficient

operation for both men and women agricultural workers (Gite *et al.*, 2009) [14].

Parameter	Male (N)	Female (N)	Remarks
 Continuous Push/Pull Limit (~30% of 5th percentile strength)	40 – 42	26 – 31	Suitable for continuous manual tools (e.g., wheel hoes)
 Initial Push Force (Two-handed, ISO 11228-2)	Up to 340	Up to 220	Acceptable starting force at moderate frequency
 Sustained Push Force (ISO 11228-2)	230	130	For repeated pushing tasks
 Initial Pull Force (ISO 11228-2)	320	230	Acceptable starting pull force
 Sustained Pull Force (ISO 11228-2)	240	140	For repeated pulling tasks
 Guideline Sustained Push (HSE – UK)	100	70	Conservative limits for frequent tasks

Unit: N = Newton (Force)

7. Ergonomic evaluation method on manual weeding

Ergonomic evaluation of manual weeding is essential to assess drudgery, physiological load, postural stress, and overall work efficiency. Since weeding is labor-intensive and often performed in bending or squatting postures, a systematic evaluation helps in tool improvement and worker safety. The major ergonomic evaluation methods are described below

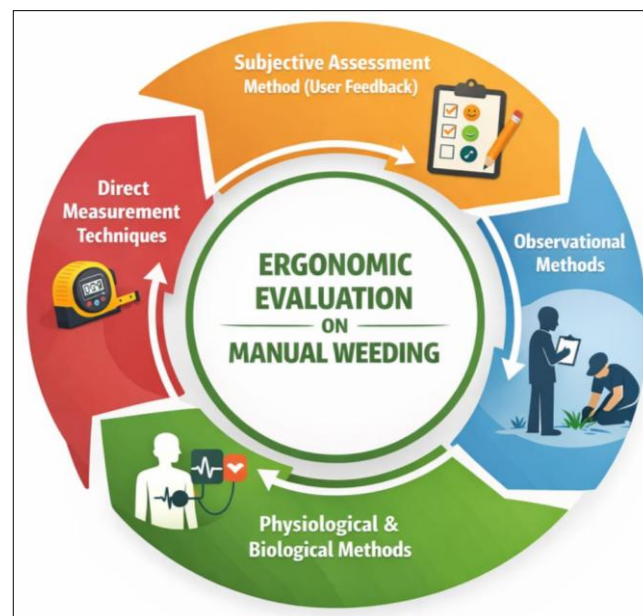


Fig 5: Schematic Diagram Ergonomic Evaluation on Manual Weeding

7.1 Subjective Assessment Method (User Feedback)

The subjective assessment method is an ergonomic evaluation approach that relies on direct feedback from workers to assess discomfort, fatigue, pain intensity, and perceived physical exertion during manual weeding tasks. Instead of measuring physiological responses through instruments, this method captures the worker's personal experience of workload and strain, making it especially useful in field conditions.

Common tools used in subjective assessment include the Rating of Perceived Exertion (RPE) scale developed by Gunnar Borg, which measures perceived physical effort; the Body Part Discomfort Scale, which identifies specific body regions experiencing pain; the Visual Analogue Scale

(VAS), which quantifies pain intensity along a graded line; and the Nordic Musculoskeletal Questionnaire (NMQ), designed to record musculoskeletal symptoms in different body parts. These methods are simple, economical, and easy to administer in agricultural settings. They help identify discomfort-prone body regions during weeding operations and allow researchers to correlate tool design, posture, and workload with the worker's perception of strain, thereby supporting ergonomic improvements.

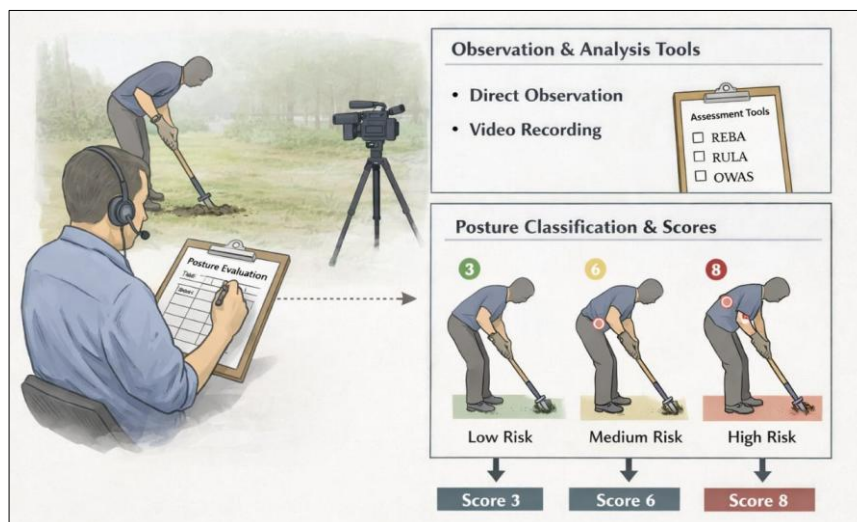


Fig 6: Observation and Analysis tools for Ergonomic Evaluation

Subjective assessment relies on worker feedback to measure perceived exertion, discomfort, and fatigue during weeding tasks. Common tools include the Rating of Perceived Exertion (RPE) scale developed by Borg, the Body Part Discomfort Scale, the Visual Analogue Scale (VAS) for pain intensity, and the Nordic Musculoskeletal Questionnaire (NMQ), which records musculoskeletal symptoms across body regions. These methods are simple, economical, and suitable for field conditions, enabling researchers to correlate tool design, posture, and workload with workers' perceived strain (Borg, 1982; Kuorinka *et al.*, 1987; Gite, Agarwal, & Yadav, 2009) [5, 29, 14]. Observational ergonomic methods are widely used to evaluate working posture and biomechanical risk during manual weeding. Techniques such as Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), and Ovako Working Posture Analysis System (OWAS) systematically analyze body posture, joint angles, muscle use, and external load to identify musculoskeletal risk levels (McAtamney & Corlett, 1993; Hignett & McAtamney, 2000) [31, 17]. These tools frequently reveal high-risk conditions in weeding operations, including excessive trunk flexion ($>20-30^\circ$), prolonged squatting, knee overloading, and wrist deviation during tool use. Recent advances in ergonomic research also incorporate video-based posture analysis, digital goniometry, biomechanical modeling, and Digital Human Modelling (DHM) using simulation platforms such as CATIA and JACK. These technologies allow estimation of spinal compression forces, joint moments, muscle activation, and reach envelopes, enabling virtual evaluation of handle height, grip diameter, and tool weight before prototype development (Dul & Weerdmeester, 2008; Karwowski, 2021; Joshi *et al.*, 2023) [11, 23]. By identifying biomechanical risk factors and integrating modern digital evaluation techniques, ergonomic

7.2 Observational Methods

Ergonomic evaluation of manual weeding is essential to assess drudgery, physiological workload, postural stress, and work efficiency, as these operations are typically performed in prolonged bending or squatting postures that increase the risk of musculoskeletal disorders. Evaluation methods generally include subjective assessment and observational techniques.

assessment supports the redesign of improved weeders such as long-handle tools, adjustable handles, and optimized grips thereby reducing drudgery, improving working posture, and enhancing occupational safety and productivity among agricultural workers.

7.3 Physiological and Biological Methods

Physiological and biological methods are objective approaches used to evaluate the internal body responses of workers during manual weeding operations. These methods measure how the cardiovascular, respiratory, and muscular systems respond to physical workload, providing a scientific basis for assessing task intensity and worker fatigue. Important physiological parameters include heart rate, oxygen consumption (VO_2), and energy expenditure, which indicate the metabolic demand and cardiovascular strain associated with weeding tasks. Higher values of these indicators generally reflect greater physical workload and faster onset of fatigue. In addition, blood lactate concentration is used to identify the transition from aerobic to anaerobic metabolism, indicating increased muscular stress during intensive work. Electromyography (EMG) is another advanced technique used to record electrical activity in muscles, allowing researchers to evaluate muscle activation patterns and fatigue levels during repetitive weeding operations. These physiological measurements help determine whether the workload exceeds safe limits for continuous agricultural work. Ergonomic guidelines suggest that sustained workload during farm activities should remain within approximately 30-35% of an individual's aerobic capacity to maintain safe physiological strain and long-term work sustainability (Astrand & Rodahl, 2003; Kroemer & Grandjean, 1997; Gite, Agarwal, & Yadav, 2009) [2, 26, 14].

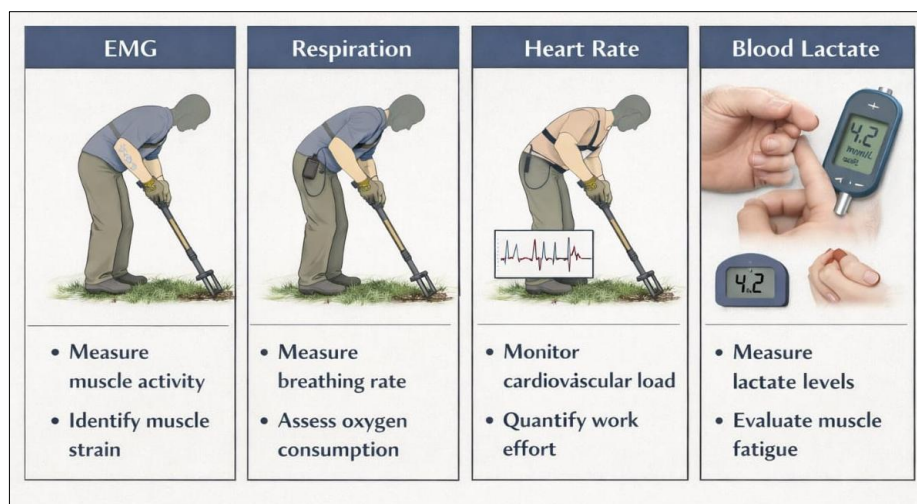


Fig 7: Physiological and Biological Methods for Ergonomic Evaluation

Modern ergonomic studies increasingly integrate portable metabolic analyzers, wearable heart-rate monitors, and wireless EMG systems to obtain real-time physiological data in field conditions, enabling more accurate assessment of tool performance and supporting the development of improved ergonomic weeding tools that reduce worker fatigue and enhance productivity (Karwowski, 2021; Joshi *et al.*, 2023) [23].

7.4 Direct Measurement Techniques

Direct measurement techniques are objective ergonomic methods that use instruments to record real-time physiological and biomechanical responses during manual weeding operations. Unlike subjective or observational assessments, these techniques provide precise quantitative data on workload and tool performance. Common measurements include heart rate monitoring to assess cardiovascular strain, oxygen consumption (VO_2) to determine metabolic workload, and energy expenditure to estimate the total physiological cost of the task. Electrocardiography (ECG) is sometimes used to monitor cardiac responses during strenuous field activities, while a hand-grip dynamometer measures grip strength and evaluates the force requirement of tool handles. Recent advances in ergonomic research also employ wearable physiological sensors, portable metabolic analyzers, and

wireless monitoring systems, which allow real-time workload assessment directly in field environments and improve the accuracy of ergonomic tool evaluation (Astrand & Rodahl, 2003; Karwowski, 2021; Li *et al.*, 2022) [2, 23, 30].

Work performance and efficiency metrics are also important for evaluating the effectiveness of weeding tools and their impact on worker productivity. Key indicators include field capacity (ha hr^{-1}), which represents the area covered per unit time, and weeding efficiency (%), which measures the proportion of weeds removed relative to the initial weed population. Postural risk improvement can be assessed through RULA and REBA score comparisons, where lower scores indicate reduced musculoskeletal strain after ergonomic intervention. For powered weeders, power consumption calculated from operating voltage and motor current is used to evaluate energy efficiency and battery performance. Additional evaluation techniques such as time-motion studies analyze work elements (pushing, pulling, turning, idle time) to optimize workflow, while the drudgery index combines physiological workload indicators with subjective discomfort ratings to quantify overall physical strain. Integrating these performance metrics with modern sensor-based monitoring systems enables comprehensive ergonomic evaluation and supports the design of efficient, low-drudgery agricultural tools (Gite, Agarwal, & Yadav, 2009; Pandey *et al.*, 2023; Kumar *et al.*, 2024) [14, 39, 27].

Table 2: Represents The types of weeder with their weeding efficiency

Sl. No.	Type of Weeder	Power Source	Weeding Efficiency (%)	Field Capacity (ha/h)	Field Capacity (ha/day)	References
1	Hand Pulling	Human	85-95	0.003-0.006	0.02-0.05	Nag & Dutta (1979)
2	Khurpi (Hand Hoe)	Human	80-90	0.005-0.008	0.04-0.06	Tiwari <i>et al.</i> (2002)
3	Traditional Hand Hoe	Human	70-85	0.006-0.01	0.05-0.08	Behera <i>et al.</i> (1993)
4	Wheel Hoe (Single/Double)	Human	75-90	0.01-0.02	0.06-0.12	Yadav & Pund (2007)
5	Twin Wheel Hoe	Human	80-92	0.015-0.025	0.10-0.18	Gite <i>et al.</i> (2003)
6	Cono Weeder (Wetland)	Human	80-95	0.02-0.04	0.12-0.20	Subramanian <i>et al.</i> (2008)
7	Rotary Weeder (Dryland)	Human	70-85	0.015-0.03	0.10-0.15	Kathirvel <i>et al.</i> (2004)
8	Power Weeder (2-3 hp petrol engine)	Engine-operated	85-95	0.05-0.10	0.30-0.60	Singh <i>et al.</i> (2010)
9	Self-Propelled Intercultivator	Engine-operated	85-95	0.08-0.15	0.50-0.90	ICAR-CIAE (2012)
10	Tractor-operated Rotary Weeder	Tractor PTO	90-98	0.20-0.40	1.20-2.50	Sharma & Singh (2014)

8. Design consideration and improvement

Design consideration is essential in manual weeders to ensure efficient performance, operator safety, and reduced physical strain. Traditional tools often cause fatigue and musculoskeletal problems due to poor design and improper working posture. By incorporating ergonomic principles such as proper handle height, grip size, tool weight, and blade geometry, the weeder can be made more comfortable and easier to use. Good design helps in maintaining a better working posture, reducing drudgery, improving work efficiency, and increasing productivity, especially for smallholder and women farmers.



Fig 8: Ergonomic Design Consideration and Improvement

8.1 Handle Design (Grip Optimization)

Modified handle designs in agricultural hand tools have been developed to reduce operator fatigue, improve comfort, and enhance work efficiency during manual farming operations such as weeding and hoeing. Traditional tools often have fixed handles that do not match the anthropometric characteristics of users, resulting in awkward postures and increased musculoskeletal strain. Ergonomic research suggests that tool handles should be designed to maintain neutral wrist posture, minimize excessive grip force, and allow efficient force transmission during operation (Pheasant & Haslegrave, 2006; Bridger, 2018) ^[41].

One common modification is the adjustable or telescopic handle, which allows the handle height to be adjusted according to the operator's body height. This design helps maintain a more upright posture and reduces excessive trunk bending and lower back strain during prolonged work. Studies on modified wheel hoes have shown that adjustable handles significantly reduce physiological workload and discomfort among agricultural workers (Sinha *et al.*, 2023) ^[51]. Another important improvement is the angled or bent handle design, typically inclined between 45° and 65°, which helps maintain neutral wrist alignment and reduces forearm muscle strain. Experimental evaluations of modified weeders have demonstrated that optimized handle angles reduce heart rate, oxygen consumption, and energy expenditure during weeding operations (Singh *et al.*, 2025) ^[50].

Anthropometric-based handle design is also widely recommended in ergonomic tool development. Research indicates that grip diameters of 30-40 mm and handle lengths of approximately 110-120 mm are suitable for most adult agricultural workers and help improve grip strength while reducing localized pressure on the palm (Chakrabarti, 1997; Kumar & Narayan, 1995) ^[28]. In addition, redesigned handles for women agricultural workers, including modified grip width and diameter, have been shown to reduce physiological strain and improve work efficiency (Sinha *et al.*, 2023) ^[51]. Improvements in handle materials, such as cushioned and non-slip grips, also enhance comfort and reduce muscular fatigue by distributing pressure more evenly across the palm (Moroney *et al.*, 1988) ^[33].

8.2 Tool Geometry

Tool geometry, including blade shape, width, cutting angle, and operating depth, plays a crucial role in determining the performance and ergonomic efficiency of manual weeding tools. Proper geometric configuration reduces soil resistance, improves soil penetration, and minimizes the muscular effort required for manual operation. In contrast, poorly designed tools increase draft force, operator fatigue, and the possibility of crop damage. According to Hu *et al.* (2024), the geometric parameters of weeding blades such as blade width, thickness, and cutting angle significantly influence the cutting efficiency and energy requirement of manual weeding implements. Optimized blade geometry allows efficient slicing of weeds while maintaining minimal disturbance to surrounding crops.

Blade shape is particularly important in determining how the tool interacts with soil and weed roots. Sweep-shaped and V-shaped blades are widely used in manual weeders because they provide effective horizontal slicing action and reduce soil resistance. These blade shapes promote cutting rather than lifting of soil, thereby reducing the draft force required for operation. Experimental studies have shown that optimized blade shapes can significantly improve weeding efficiency and field capacity while maintaining acceptable physiological workload for the operator (Chethan *et al.*, 2018; Hu *et al.*, 2024) ^[8, 18]. Blade width must also be selected according to crop row spacing to prevent crop injury while ensuring efficient weed removal. Studies on improved weeders indicate that blade widths between 120 and 200 mm are suitable for most row crops and help achieve higher field efficiency without increasing operator workload (Yadav & Pund, 2007; Chethan *et al.*, 2018) ^[52, 8]. The cutting angle of the blade also plays a significant role in determining tool performance. A proper cutting angle improves soil penetration and reduces draft force during operation. Research on mechanical weeding tools indicates that cutting angles between 15° and 30° provide effective slicing action and reduce energy consumption during weed removal (Hu *et al.*, 2024; Shirwal, 2020) ^[18, 47]. Similarly, maintaining an appropriate operating depth of 2-5 cm is sufficient to remove shallow-rooted weeds while minimizing soil disturbance and resistance. In push-pull weeders equipped with wheels, wheel diameter also influences tool performance. Larger wheels, typically 200-300 mm in diameter, reduce rolling resistance, improve tool stability, and help the operator maintain a comfortable working posture during field operation (Panigrahi *et al.*, 2025) ^[40]. These geometric optimizations contribute

significantly to improving operational efficiency and reducing drudgery in manual weeding tasks.

8.3 Weight and Balance Considerations

The weight and balance of agricultural hand tools are critical factors affecting operator fatigue, energy expenditure, and overall work productivity. Tools that are excessively heavy increase muscular strain and

cardiovascular workload during prolonged manual operations. Ergonomic studies recommend that manual weeding tools should ideally weigh between 4 and 8 kg, which allows efficient operation while minimizing physical stress on the operator (Singh *et al.*, 2023). Maintaining tool weight within this range helps reduce physiological workload and improves operator endurance during repetitive field tasks.

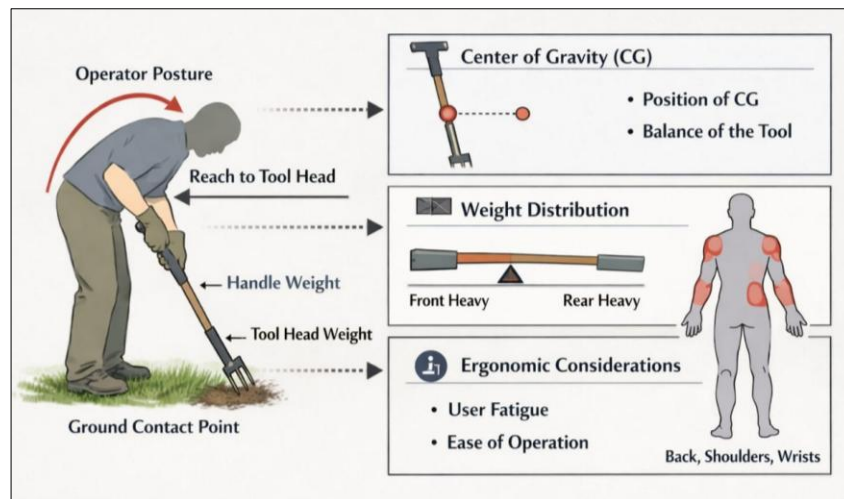


Fig 9: Weight and Balance Considerations for Ergonomic Evaluation

Proper mass distribution within the tool is also essential for maintaining stability and reducing operator fatigue. The centre of mass (CM) should ideally be located near the wheel axle or close to the hand grip to minimize lifting effort and ensure balanced movement during push-pull operations. Poorly balanced tools create excessive torque on the operator's arms and lower back, increasing the risk of fatigue and musculoskeletal disorders. Studies on ergonomically designed weeders have shown that balanced tools significantly reduce push force requirements and improve control during operation (Singh *et al.*, 2016; Panigrahi *et al.*, 2025) ^[40].

Recent technological advancements in agricultural tool design emphasize the use of lightweight and high-strength materials, such as aluminium alloys, hollow steel frames, and composite structures. These materials reduce the overall mass of the implement while maintaining structural durability and operational stability. According to Hu *et al.* (2024), improved structural design combined with lightweight materials can significantly reduce the physiological workload of operators and increase field efficiency during manual weeding operations. Such design improvements help reduce drudgery, improve ergonomic comfort, and enhance the overall productivity of small-scale farming systems.

8.4 Anthropometric Considerations (Indian Operators)

Anthropometric considerations are fundamental in the ergonomic design of agricultural tools, as they ensure compatibility between human body dimensions and the physical characteristics of the tool. Designing tools based on anthropometric data helps improve operator comfort, reduce

physical strain, and enhance operational efficiency during manual agricultural activities. In agricultural ergonomics, it is generally recommended that tools should accommodate users within the 5th to 95th percentile of the target population, ensuring that both smaller and larger operators can perform tasks safely and effectively (Chakrabarti, 1997; Pheasant & Haslegrave, 2006) ^[41]. Failure to consider anthropometric variability often results in poor working posture, increased muscular effort, and a higher risk of musculoskeletal disorders among farm workers.

Operator height is a key anthropometric parameter that influences tool design, particularly for implements such as manual weeders and hoes. The average stature of Indian agricultural workers generally ranges between 150 and 175 cm, and tools should therefore be designed to accommodate this range. Improper handle height forces workers to adopt excessive trunk bending or shoulder elevation, leading to discomfort and increased loading on the lumbar spine and shoulder muscles. Adjustable handle mechanisms are therefore recommended to allow operators to maintain a near-upright posture during work (Bridger, 2018; Sinha *et al.*, 2023) ^[51].

Arm reach and shoulder breadth also play an important role in determining the appropriate handle length and spacing for bilateral agricultural tasks. If handle spacing does not match the operator's shoulder breadth, it may lead to overextension of the arms or asymmetric loading on the upper limbs. Studies on ergonomic agricultural tools indicate that proper alignment between handle spacing and shoulder width improves force transmission and reduces fatigue during repetitive push-pull operations (Kroemer & Grandjean, 1997; Singh *et al.*, 2025) ^[26, 50].



Fig 10: Anthropometric Considerations for Ergonomic Evaluation

Hand dimensions are another critical factor in tool design, particularly in determining the appropriate grip diameter. Grip sizes that are too small or too large can significantly reduce grip strength and increase muscular activity in the forearm muscles. Research suggests that grip diameters between 30 and 40 mm are optimal for most adult users and allow maximum grip strength with minimal muscular effort (Chakrabarti, 1997; Kumar & Narayan, 1995) [28]. Properly designed grips increase the contact area between the hand and the handle, thereby reducing localized pressure and minimizing fatigue during prolonged manual operations.

Anthropometric design must also consider the natural working posture of the operator. Agricultural tools should allow workers to maintain neutral or near-neutral positions of the trunk, arms, and wrists during operation. Excessive trunk flexion, lateral bending, or wrist deviation can increase mechanical stress on joints and soft tissues, contributing to musculoskeletal disorders. Ergonomic guidelines suggest that trunk flexion during manual agricultural work should ideally be limited to less than 20° , while elbow joint angles should remain within 90° - 120° to allow efficient force application without overloading the shoulder or forearm muscles (Bridger, 2018; David, 2005) [10].

In addition, prolonged squatting or kneeling postures are commonly associated with manual weeding operations and can lead to lower limb fatigue, reduced blood circulation,

and increased discomfort. Modern ergonomic tool designs therefore aim to enable standing or semi-bent postures during weeding operations, which significantly reduce lower limb strain and improve work endurance (Panigrahi *et al.*, 2025) [40]. Adjustable handles, optimized grip dimensions, and proper handle spacing are among the key design strategies used to accommodate anthropometric variability among agricultural workers. Incorporating these considerations into tool design helps reduce drudgery, improve operator safety, and enhance the overall efficiency of manual farming operations.

8.5 Safety & Usability of Equipment

Safety and usability are essential aspects of ergonomic agricultural tool design, as they directly influence operator protection, ease of operation, and long-term efficiency during manual farming tasks. Proper safety features help minimize the risk of injuries such as cuts, abrasions, and accidental contact with moving parts. For instance, tools should be designed without exposed sharp edges and should include guards for rotating components such as blades or wheels to protect the operator's hands and fingers during operation. Smooth finishing of the tool frame without projecting bolts or sharp corners also prevents skin abrasions and reduces the risk of clothing snagging. In addition, non-slip handle grips made from rubberized or textured materials improve control of the tool, especially

under sweaty or wet conditions, thereby reducing the chances of slips or strain injuries. A stable wheel base is another important safety feature, as it helps maintain balance, prevents tipping, and ensures even load distribution during push-pull operations (Bridger, 2018; Kroemer & Grandjean, 1997) ^[26].

Usability features further enhance the practicality and efficiency of agricultural tools. Tools designed with modular components allow easy assembly, repair, and maintenance, reducing downtime during field operations. Simple blade replacement systems enable quick replacement of worn or damaged blades without requiring specialized tools, thereby improving operational efficiency. Low maintenance requirements, achieved through durable construction and corrosion-resistant materials, reduce maintenance costs and increase the service life of the implement. Clear operating instructions and ergonomic guidelines also play an

important role in minimizing operator errors and ensuring safe and effective tool usage (Pheasant & Haslegrave, 2006) ^[41].

Recent design improvements in agricultural tools include the incorporation of protective blade covers, which protect users when the tool is not in operation or during transportation. Rounded frame edges are also recommended to reduce the risk of impact injuries during handling. In addition, anti-vibration systems and shock-absorbing grips are increasingly used to reduce hand-arm vibration and fatigue during prolonged use. Safety decals and warning labels are also commonly added to provide visual guidance and hazard awareness for operators. Together, these safety and usability improvements contribute to safer working conditions, reduced injury risk, and enhanced productivity in manual agricultural operations.

Table 3: Comparative Analysis of Ergonomically Developed Manual Weeders

Weeder Type / Study	Design Features / Improvements	Performance & Ergonomic Outcomes	Key References
Modified Chisel Weeder	Adjustable handle (45-65°), lightweight frame (4.5 kg), optimized cutter blade	Lower heart rate, oxygen consumption, energy expenditure; 15-28% lower discomfort vs. modified hoe	Singh <i>et al.</i> (2025)
Modified Hoe Weeder	Adjustable handle, optimized blade, lightweight frame	Improved comfort over traditional hoe; still higher strain than chisel weeder	Singh <i>et al.</i> (2025)
Wheel Hoe (Manual)	Traditional wheel-based design	Highest field capacity among evaluated manual tools; moderate discomfort levels	Kumar <i>et al.</i> (2002)
Crescent Hoe	Traditional hand weeder	Lower area coverage compared to wheel hoe; similar discomfort levels	Kumar <i>et al.</i> (2002)
Kasola (Spade Type)	Traditional spade weeder	Least energy expenditure but lowest output and slowest field coverage	Kumar <i>et al.</i> (2002)
Push-Pull Weeders (RPW, WH, WFW)	Rotary peg, wheel hoe, wheel finger weeder	Wheel finger weeder (WFW) had highest field capacity and weeding index; lower required push force	Behera <i>et al.</i> (2007)
Modified Wheel Hoe (Women-oriented)	Varied blade sizes + multiple handle widths	Reduced heart rate, oxygen consumption; improved posture and lower discomfort scores for female operators	Sinha <i>et al.</i> (2023)
Ergonomic Wheel Hoe (Female Customized)	Blade size 10% reduction + broader handle width	Reduced overall discomfort and physiological strain; improved ergonomic classification	Sinha <i>et al.</i> (2023)
Four-Wheel Weeder (Wide Row)	Four wheels + swinging handle for wider row spacing	Improved lateral stability, uniform cutting depth, reduced push effort	Singh <i>et al.</i> (2013)
Innovative Blade & Tine Wheel Weeders	Wheel hoe with different blade/tine configurations	Different designs affected field capacity and plant damage rates; some improved ergonomic efficiency	Ergonomic weeder eval., MDPI Sustainability (2022)*

9. Future Adaptation for Ergonomic Assessment of Manual Weeders

Future adaptation in the ergonomic assessment of manual weeders is expected to focus on integrating advanced digital technologies, smart sensing systems, and data-driven analysis methods to improve operator safety and tool performance. With the development of digital agriculture, ergonomic evaluation is increasingly supported by intelligent monitoring systems that can collect and analyze real-time data related to posture, workload, and environmental conditions. Smart sensor technologies and Internet-of-Things (IoT) devices can monitor operator movements, physical workload, and working conditions during field operations, enabling more accurate ergonomic assessment compared with traditional observational methods. These technologies allow continuous monitoring and data collection, which can help researchers identify ergonomic risks and improve the design of manual weeders and other agricultural tools (Siddharth *et al.*, 2025) ^[48].

Another important future direction is the application of artificial intelligence and machine learning for automated

ergonomic evaluation. AI-based posture recognition systems using computer vision and deep learning algorithms can analyze workers' body movements and identify non-neutral postures during agricultural tasks. For example, recent research demonstrated that AI-enabled posture classification systems can automatically detect ergonomic risks in agricultural activities and help prevent musculoskeletal disorders among workers. Such intelligent systems can significantly enhance the accuracy and efficiency of ergonomic assessment and support the development of safer agricultural tools (Kapse, Wu, & Thamsuwan, 2024) ^[22].

Wearable technologies and motion-capture systems are also expected to play a major role in future ergonomic studies. Devices such as inertial measurement units (IMUs), smart wearable sensors, and physiological monitoring systems can record parameters such as body posture, movement patterns, fatigue levels, and energy expenditure in real time. These wearable systems enable predictive risk assessment and provide continuous feedback to operators and researchers, allowing early detection of ergonomic hazards during

manual agricultural operations like weeding (Apicella & Tarabella, 2025) ^[1].

Furthermore, future ergonomic assessment may incorporate robotics, human robot interaction, and digital simulation technologies. Advances in agricultural robotics and intelligent machinery allow collaborative work between humans and machines, where robotic systems assist farmers in physically demanding operations while maintaining ergonomic safety. Human-robot interaction frameworks can dynamically monitor worker posture and adjust machine operations accordingly, thereby reducing operator workload and improving occupational safety in agricultural environments (Benos *et al.*, 2023) ^[4].

Recent ergonomic research increasingly Modelling and Simulation Techniques uses digital modelling and simulation tools to evaluate agricultural tool performance before field testing. These tools allow researchers to analyze operator posture, joint stress, and human-tool interaction in virtual environments, improving design accuracy and

reducing ergonomic risks. According to Padhiary, Roy, and Kumar (2025), simulation software helps engineers optimize ergonomic parameters through virtual testing and AI-assisted automation, reducing design errors and minimizing the need for extensive field trials. Similarly, studies reported in the journal *Ergonomics* indicate that simulation approaches are widely used to enhance agricultural machinery design and evaluate operator safety and comfort. Motion capture technologies and wearable sensors are increasingly used for ergonomic assessment of agricultural tasks. These systems monitor body posture, joint angles, and movement patterns during field operations. Apicella and Tarabella (2025) reported that wearable devices such as inertial measurement units (IMUs), smart glasses, and motion sensors can provide real-time data on worker posture, fatigue, and physical workload. Such technologies are particularly useful in labor-intensive operations like manual weeding, where continuous monitoring helps identify ergonomic risks and improve tool design.

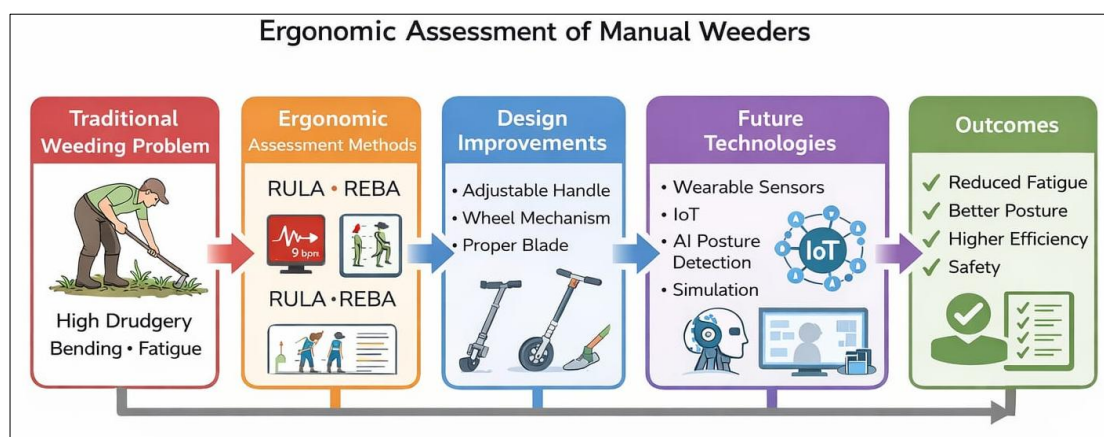


Fig 11: Flow chat of Evaluation Adaptation for Ergonomic Assessment of Manual Weeders

Artificial intelligence and machine learning technologies are increasingly applied to automate ergonomic assessment and posture analysis. Kapse, Wu, and Thamsuwan (2024) developed an AI-based posture classification system using computer vision and machine learning models to detect trunk posture during agricultural work. The system achieved high accuracy and demonstrated the potential of AI in improving ergonomic monitoring and preventing musculoskeletal disorders. Similarly, research published in *E3S Web of Conferences* (2024) showed that AI-based systems can analyze large datasets from sensors to automatically detect ergonomic risks and improve safety interventions in farming operations.

Virtual reality (VR) and augmented reality (AR) technologies are emerging as effective tools for ergonomic evaluation and training in agriculture. These technologies allow researchers to study operator posture, machine interaction, and safety conditions within simulated environments before field testing. A systematic review published in *Computers and Electronics in Agriculture* (2025) highlighted that VR and AR are increasingly used for simulation, operator training, and ergonomic analysis of agricultural machinery, helping to evaluate tool performance and operator comfort while reducing testing time and cost.

10. Conclusion

Manual weeding remains a crucial but highly labor-intensive operation in Indian agriculture, particularly among

smallholder farmers who rely on traditional hand tools. These conventional tools often require prolonged bending and repetitive movements, leading to fatigue, musculoskeletal disorders, and reduced work efficiency. The application of ergonomic principles in the design of manual weeders such as optimized handle geometry, appropriate tool weight, anthropometric compatibility, and improved blade design—can significantly reduce physiological workload and enhance operator comfort. Ergonomic evaluation methods, including subjective assessment, observational techniques, and physiological measurements, play an important role in identifying risk factors and improving tool performance. Comparative studies of improved weeders demonstrate that ergonomic modifications can reduce drudgery, improve field capacity, and increase productivity. Furthermore, emerging technologies such as digital modelling, wearable sensors, artificial intelligence, and virtual reality offer new opportunities for advanced ergonomic assessment and tool optimization. Therefore, integrating ergonomic design principles with modern technologies will be essential for developing efficient, safe, and user-friendly manual weeders that support sustainable and productive agricultural systems in India.

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