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Reducing musculoskeletal strain in agriculture: An evaluation of an improved hoe design

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ABSTRACT

Manual weeding remains a physically demanding agricultural task, often contributing to musculoskeletal disorders (MSDs) among farm workers due to awkward postures and poorly designed traditional tools. This study aimed to evaluate the ergonomic performance of an improved hoe design tailored specifically for male farm workers. A within-subject experimental design was adopted, involving 20 male participants with over five years of field experience. Comparative assessments were made between the traditional and improved hoe based on spinal deviation, grip fatigue, physiological cost, musculoskeletal discomfort, perceived exertion, and weeding efficiency. The improved hoe, developed using anthropometric and biomechanical principles, featured modifications including a longer handle (125 cm), optimized blade angle (75°), and comfortable grip dimensions. Results indicated a notable reduction in head and trunk flexion angles, grip fatigue, physiological cost, and lower back pain. Furthermore, the improved hoe was associated with enhanced weeding efficiency (80%) and greater user comfort. Designing an ergonomically optimized tool posed challenges such as accommodating varied body dimensions, balancing tool weight with functional strength, and ensuring adaptability to different soil conditions. Despite these constraints, the study contributes significantly by providing a validated ergonomic framework for agricultural tool design that minimizes biomechanical strain and enhances worker safety, comfort, and productivity. These findings underscore the importance of ergonomic tool redesign in reducing biomechanical stress and improving occupational health and productivity in agriculture.

Keywords: *Ergonomics, Manual Weeding, Improved Hoe, Musculoskeletal Disorders, Weeding Efficiency, Ergomaster, Health Hazards, Working Posture.*

INTRODUCTION

Agriculture remains a labor-intensive sector in many developing regions, where manual operations such as weeding are still widely practiced. Among these, weeding is one of the most ergonomically demanding tasks due to its repetitive nature and the awkward postures it often entails. Workers are typically required to bend, kneel, twist, or maintain squatting positions for prolonged periods, which increases the likelihood of developing musculoskeletal disorders (MSDs)[1] [2]. These conditions not only compromise the health and well-being of farm workers but also have direct implications on productivity, work efficiency, and long-term occupational sustainability[3][4].

One of the major contributors to these occupational health risks is the continued reliance on traditional hand tools such as hoes and khurpis, which are often locally made and lack ergonomic consideration in their design[5]. These tools are generally produced using bamboo handles and mild steel blades, with little standardization in length, weight, or grip dimensions. As a result, users experience strain in the upper limbs, shoulders, and lower back due to the excessive physical effort required to operate these tools effectively [6][7]. Poor tool balance, suboptimal handle dimensions, and inappropriate blade angles exacerbate the biomechanical load on the body during repetitive tasks, leading to cumulative trauma and increased risk of injury[8][9].

Addressing these ergonomic shortcomings through tool redesign has been widely recognized as an effective preventive strategy. Ergonomic interventions not only reduce physical strain and discomfort but also enhance task performance, job satisfaction, and worker safety[1]. A user-centered design approach beginning with identification of task-specific biomechanical risks and user discomfort, followed by tool reconfiguration based on ergonomic principles is considered essential to mitigate these risks [2][4]. In light of these challenges, the present study aims to evaluate an ergonomically improved hoe design tailored for male farm workers engaged in manual weeding. The redesign focuses on optimizing handle length, grip diameter, tool balance, and blade geometry, guided by anthropometric and biomechanical data. The objective is to assess the impact of the improved hoe design on physical exertion, posture, and perceived discomfort, in comparison to traditional tools. Such evidence-based design modifications are critical for reducing work-related MSDs, improving occupational well-being, and promoting sustainable manual agricultural practices.

METHODOLOGY

Participant Selection

Twenty male farm workers, aged between 25 and 40 years and possessing over five years of experience in weeding activities, were purposively selected for this study. All participants were physically healthy, free from any musculoskeletal disorders, and had an average shoulder height of 131.4 cm. Prior to the experiment, each worker was thoroughly informed about the

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study's objectives and procedures, and their informed consent was obtained.

Experimental Design

A within-subject experimental design was employed to compare the ergonomic performance of the existing hoe with the newly improved design. Each participant carried out weeding tasks using both tools in six different treatment combinations. Each session lasted 35 minutes, with adequate rest periods in between to reduce the effects of fatigue and ensure accurate evaluation.

Design Optimization of the Improved Hoe

The improved hoe was developed through a systematic design optimization process grounded in ergonomic principles and user-centered feedback. Key anthropometric data of male farm workers were analysed to determine the optimal dimensions for comfort and efficiency during weeding tasks. The handle length was increased to 125 cm to promote a more upright working posture, reducing the need for excessive forward bending and thereby minimizing lower back strain. The blade angle was adjusted to 75°, aligning better with the natural movement arc of the upper limbs, which facilitated efficient soil engagement with reduced physical effort. Additionally, the blade size was expanded to 32 cm × 20 cm, allowing for a broader coverage area per stroke, thus enhancing weeding productivity. The handle circumference was set at 3.6 cm to fit comfortably within the average male hand grip range, improving control and reducing hand fatigue during prolonged use. Each design element was iteratively tested and refined through field trials, ensuring that the final tool configuration not only addressed biomechanical stress but also improved user satisfaction and task efficiency. This holistic approach to tool design optimization ensured a balance between ergonomic comfort, operational effectiveness, and long-term usability in agricultural weeding activities.

Evaluation Parameters and Measurement Tools

To assess the ergonomic impact of the improved hoe compared to the traditional tool, a comprehensive set of parameters was measured using both objective instruments and subjective ratings:

- **Spinal Deviation:** Workers' postures during the weeding activity were recorded through video and photographs. The degree of spinal deviation was quantified using Ergomaster software, providing an indicator of postural strain.

- **Grip Strength:** Handgrip strength was measured before and after weeding using a dynamometer. The reduction in grip strength after the task served as a measure of muscle fatigue.

- **Physiological Cost:** Heart rate monitors recorded participants' heart rates before and immediately after the task. An increase in heart rate was used to estimate the physical workload imposed by each hoe.

- **Musculoskeletal Discomfort:** Post-task discomfort was documented using a human body map and a 3-point pain scale (1 = just noticeable, 2 = moderate, 3 = intolerable). This helped identify the specific body areas affected by tool use.

- **Rate of Perceived Exertion (RPE):** Participants rated their perceived exertion using a standardized 5-point scale ranging from very light to very heavy effort.

- **Ease of Comfort:** A simple 3-point scale was used to gauge user comfort during operation (1 = very uncomfortable, 2 = comfortable, 3 = very comfortable).

- **Weeding Efficiency:** This refers to the effectiveness of a particular tool or method in removing weeds from a given area. It is a measure of how well a weeding technique or tool performs its intended function, which is to control or eliminate weeds in agricultural or gardening settings.

Efficiency of weed removal was calculated using:

Weeding efficiency (%) = $N = (W_1 - W_2) / W_1 * 100$ where,

N= Weeding efficiency in percentage

W_1= Area given for the operation covering weeds

W_2= Area left after the operation covering weeds

Grip Dynamometer

Heart rate monitor

Equipment Used to Evaluate the Workers Performance in the Existing and the Improved Hoe

Ethics Statement

The study was approved by the Institutional Ethics Committee (IEC) for Human Studies (H), College of Community Science, Assam Agricultural University, Jorhat (Approval No. AAU/CCSc/FSN/IEC(H)/20-HDJ-10/24-25/05, dated 10/09/2024). All participants provided written informed consent. The research was conducted in accordance with the Declaration of Helsinki.

RESULT AND DISCUSSION

Finalization of the design concept

The field trial for the improved hoe was carried out in the studied area and compared with the existing hoe. The functionality of the improved hoe was conducted through a participatory approach. The workers' feedbacks were collected again and accordingly modification were incorporated in the hoe. Based on the suggestions of the workers, the modification in the improved hoe was made as presented in (Table 1, plate 1).

The newly designed improved hoe was based on the dimension of the blade, the angle between shaft and the handle, circumference of the handle and the length of the handle. The cutting edge of the blade was broadened to remove more weeds at a time. Circumference of the handle was made such that a power grip was possible for most of the workers. Handle length was adjusted according to the mean shoulder height of the workers so that there is no need to bend a lot while doing the task. Angle between shaft and handle was kept in such a way that less force was used while performing the task.

Table 1: Dimension details of the improved hoe over existing hoe

Sl. No.	Specification	Existing tool	Improved tool
1.	Weight (Kg)	1.26	1.20
2.	Blade size Length X Width (cm)	23 X 18	32 X 20
3.	Handle length (cm)	110	125
4.	Handle circumference	13	11.3
5.	Angle	85^0	75^0
6.	Material used	Iron blade with Bamboo handle	Iron blade with Bamboo handle

PLATE 1 IMPROVED HOE

i.) Angle of deviation

From the analyses of data in Ergomaster, a significant decrease in the angle of deviation was observed between the existing and improved hoe. Angle of deviation was found more when weeding activity was performed with existing hoe i.e., 83 degrees for head flexion and 15 degree for trunk flexion as compared to the improved hoe (76 degrees for head flexion and 10 degrees for trunk flexion) as presented in Table 2 and Fig. 1

Table 2: Comparison of angle of deviation of the spine among Existing and Improved hoe

	Angle of deviation of the spine		
	Existing hoe	**Improved hoe**	**Decrease in deviation**
Head Flexion	83^0	76^0	-7^0
Trunk Flexion	15^0	10^0	-5^0

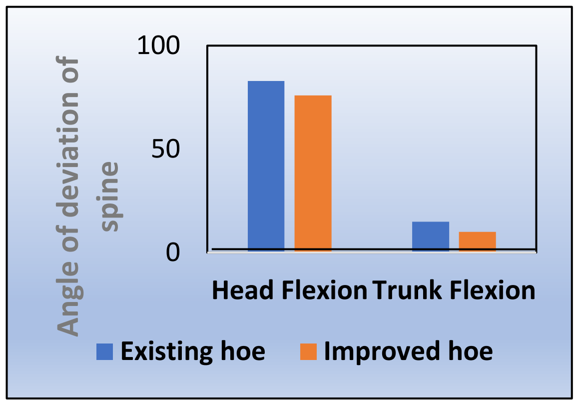

FIG 1 ANGLE OF DEVIATION OF SPINE

ii) Grip fatigue

There was a decrease in grip strength after performing the weeding activity with existing hoe. Grip fatigue was found more when weeding activity was performed with the existing hoe i.e., 18.944 percent for the right hand and 17.58 percent for the left hand as compared to the improved hoe (16.228 percent for right hand and 13.607 percent for the left hand) as presented in Table 3 and Fig. 2

Table 3: Comparison of grip strength among Existing and Improved hoe

Grip fatigue	Existing hoe	Improved hoe	Significant reduction percentage
Right hand	18.944 ± 8.81	16.228 ± 9.651	-2.716
Left hand	17.58 ± 9.104	13.607 ± 7.460	-3.974

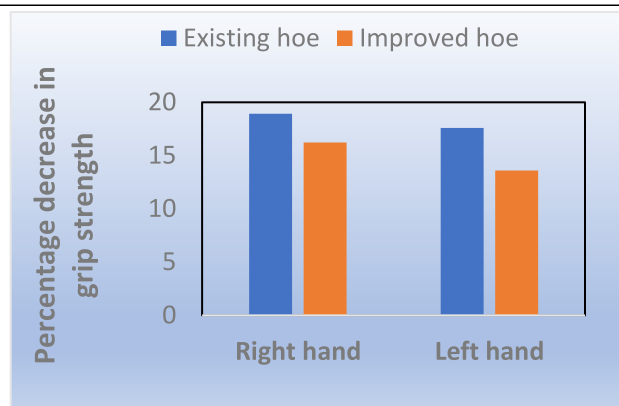

FIG. 2 EVALUATION OF GRIP FATIGUE

iii) Physiological cost of work

Physiological cost of work while performing the activity with the existing hoe was found 31.98 percent more as compared to the improved hoe. Significant reduction of 13.11 percent in Energy expenditure was found when weeding was performed with improved hoe over the traditional hoe as presented in Table 4 and Fig 3.

Table 4: Comparison of physiological cost of work among Existing and Improved hoe

Heart Rate	Existing hoe	Improved hoe	Significant reduction percentage
Average WHR (b.min^{-1})	123.9 ± 11.27	114.9 ± 11.27	-7.23
Average EE (kj.min^{-1})	10.980 ± 1.79	9.54 ±1.79	-13.11
Average PCW	41.61 ± 15.50	28.3 ± 12.50	-31.98

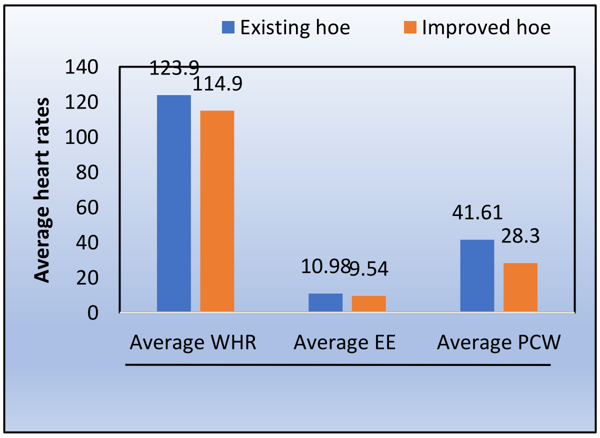

FIG 3 EVALUATION OF PHYSIOLOGICAL COST OF WORK

iv) Response of body pain of the workers with existing and improved hoe

The response of the body pain was analysed with a three-point rating scale (i.e., just noticeable-1, moderate pain-2, and intolerable pain-3) to determine the musculoskeletal problems of the workers with the help of a body map (presented in Table 5).

Table 5: Percentage reduction in musculoskeletal problems while working with existing and improved hoe

Body pain	Existing hoe	Improved hoe	Significant reduction in percentage
Neck pain	1.65	1.5	-9.09
Shoulders pain	1.85	1.7	-8.10
Elbows pain	1.65	1.65	0
Wrist/hands pain	1.25	1.15	-8
Upper back pain	1.7	1.55	-8.82
Lower back pain	2.05	1.75	-14.63
Hips/thighs pain	1.2	1.1	-8.33
Knees pain	1.85	1.85	0
Ankles/feet pain	1.15	1.15	0

Significant reduction in the body pain was observed in the improved hoe relating to lower back pain (14.63 percent) followed by neck pain (9.09 percent), upper back pain (8.82 percent), thigh pain (8.33 percent), shoulder pain (8.10 percent), and hand pain (8 percent) were observed.

v) Perceived exertion of weeding activity in the existing and improved hoe

Modified five-point rating scale (very light-1, light-2, moderately heavy-3, heavy-4, very heavy-5) of the rate of perceived exertion (RPE by Varghese *et al.,* 1994) was used to assess exertion perceived by the workers while using the existing and improved hoe.

The analysis of the response as presented in Fig. 4 reveals that the rate of perceived exertion among farm workers with the improved hoe was perceived as 50 percent 'light' followed by 30 percent 'very light' and 20 percent 'moderately heavy' compared to the existing hoe (60 percent 'moderately heavy', 30 percent 'heavy', and 10 percent 'very heavy').

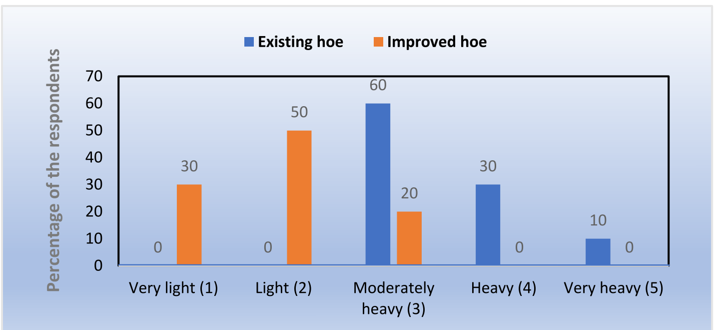

Fig 4: Rating of Perceived Exertion in Existing and Improved Hoe

i) Weeding efficiency

Weeding efficiency was evaluated by measuring the area covered and the weeding effectiveness using both the existing and improved weeding hoes. The improved hoe covered a larger area, reaching 800 sq. ft, compared to 720 sq. ft with the existing hoe within the same time period. Additionally, the weeding efficiency of the improved hoe was 80 percent, while the existing hoe achieved 72 percent. Based on these results, it was determined that the quality of work performed with the improved hoe was superior to that of the existing hoe. (Table 6).

Table 6: Weeding efficiency of existing and improved hoes

Parameters	Existing hoe	Improved hoe
Area covered (sq. Ft)	720	800
Weeding efficiency (%)	72	80

Conclusion

The ergonomic evaluation of the improved hoe design demonstrates significant benefits over the traditional tool in reducing physical strain and enhancing work efficiency among male farm workers engaged in manual weeding. Key improvements—such as optimized handle length, blade angle, and grip dimensions—effectively minimized spinal deviation, grip fatigue, physiological workload, and musculoskeletal discomfort, particularly in the lower back and upper body. The rate of perceived exertion was also lower with the improved hoe, and weeding efficiency increased by 8 percent compared to the traditional version. These findings affirm the value of user-cantered ergonomic interventions in agricultural tool design to promote worker health, comfort, and productivity. Implementing such improvements at a broader scale could play a crucial role in sustaining manual labour practices while mitigating health risks in agricultural sectors of developing regions.

Recommendations

- **Expand Regional Applicability:** Redesigned tools can be tested in diverse agricultural regions across India to assess their effectiveness in various farming environments and conditions.

- **Long-Term Health Impact Studies:** Long-term research may help evaluate the sustained effects of ergonomic tool use on reducing musculoskeletal disorders and improving worker health over time.

- **Scalability for Larger Farms:** Exploring the scalability of these ergonomic interventions in larger, mechanized farming operations may help adapt the tools for broader agricultural contexts.

- **Collaboration with Local Communities:** Local farming communities and cooperatives could be engaged for feedback and iterative improvements on ergonomic tool designs, ensuring that solutions are tailored to regional needs.

Further Scope and Limitation of the study

The present study was limited to manual hand tools only

- Future studies could investigate mechanized farming equipment that could further improve efficiency
- Further exploration of ergonomic tool design can be extended to accommodate diverse farming practices and conditions across various regions of India

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Disclosure statement

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