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Development and Performance of Four-Wheel and Battery-Assisted Weeders for Wide-Row Crops

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Weed management is an important operation in crop production, particularly in wide-row vegetable and field crops where manual weeding is laborious, time-consuming and physically demanding. The two source studies examined a four-wheel manually operated weeder and its subsequent battery-assisted development for wide-row crops. The 2016 design introduced four-wheel support, a swinging handle and slicing-type blades to improve depth control, lateral stability and operator ergonomics. The manual machine weighed 9.5 kg, used a 250 mm cutting width and achieved 95–100% weeding efficiency under the reported field conditions. The later battery-assisted machine incorporated a 250 W, 24 V brushed DC motor, a 24 V, 14 Ah battery system, power transmission, drive wheels and a swinging handle. It achieved an average field capacity of 0.0554 ha/h at 2.52 km/h with 97.5% weeding efficiency and reduced the muscular workload required from the operator. Together, the studies show a logical progression from ergonomic mechanical design to auxiliary electrical power for increasing output and reducing drudgery. The evidence also indicates that soil condition, draft, operating speed, tool geometry and battery capacity strongly influence performance. The synthesized findings are relevant to small and marginal farmers cultivating wide-row crops.

Keywords: four-wheel weeder; battery-assisted weeder; mechanical weeding; wide-row crops; ergonomics; drudgery reduction; field capacity; weeding efficiency.

Introduction

Weed control is a major requirement in crop production because weeds compete with crops for resources and can make field operations difficult. The 2016 study notes that weed control may be achieved by mechanical, chemical, biological and cultural approaches, while emphasizing the practical advantages of mechanical weeding. Mechanical tools can loosen the soil surface and support aeration and moisture conservation, whereas chemical weed control may involve cost, selectivity and environmental concerns. In vegetable production, manual weeding is particularly tedious because of labor requirements, time consumption and the need for repeated operations. The first source study identified a specific design gap: conventional single- and twin-wheel hand weeders were mainly suited to narrower row spacings and had limitations in uniform depth control and lateral stability. Wide-row crops, including many vegetables, are generally planted at spacings above 300 mm. Therefore, the authors developed a four-wheel weeder using an ergo-mechanical approach. The second study built on this concept by adding battery-assisted propulsion so that the machine could carry a greater share of the workload while retaining the four-wheel and swinging-handle arrangement.

Need for Four-Wheel Weeding Technology

The source articles frame mechanical weeding as an alternative to labor-intensive manual operations. Existing hand-operated weeders were reported to be more suitable for relatively narrow rows, whereas wide-row vegetable crops required a machine that could operate between rows without damaging the crop. The 2016 study therefore targeted crops planted at 300 mm and above and selected a 250 mm cutting width. Examples identified by the authors include pea, lobia, okra, chilli, capsicum, cauliflower, cabbage and French bean. A central limitation of conventional wheel-supported weeders was instability. Uneven or variable depth of cut changes the force needed from the operator, while lateral instability creates additional static loading. The researchers also recognized that a fixed handle does not adequately accommodate the dynamic movement of a worker during push-pull operation. These problems led to the use of four wheels for greater stability and a swinging handle for improved adaptation to operator movement.

ERGO-MECHANICAL DESIGN APPROACH

The 2016 machine combined ergonomic measurements of men and women agricultural workers with mechanical design calculations. The equipment was intended to remain below approximately 10 kg, corresponding to the stated ergonomic criterion based on the body weight of farm women. The final prototype weighed 9.5 kg. Commercial HDPE wheels were used to reduce wheel weight, while aluminium was used for part of the tool-bar structure. These material choices helped reduce the overall mass while retaining a rigid working frame.

The design adopted push-pull operation, allowing the worker to alternate the direction of effort. The swinging handle was introduced because the handle angle naturally changes during field work. The reported optimum handle length was approximately 1,220 mm, with a T-type grip selected for transmitting force along the handle. The blade arrangement was also important: two slicing blades were arranged to form a pointed centre, reducing shearing resistance and helping the machine cut weeds at shallow depth.

MAIN TECHNICAL FEATURES OF THE MANUAL FOUR-WHEEL WEEDER

PARAMETER	REPORTED SPECIFICATION
Overall dimensions	1480 × 270 × 300 mm
Weight	9.5 kg
Wheel diameter × width	300 × 50 mm
Wheel base	260 mm
Ground clearance	125 mm
Handle length	1220 mm
Cutting width	about 250 mm
Number of shanks / blades	2 / 2
Maximum working depth	about 20 mm

Design Principles and Ergonomics

The four-wheel weeder was designed around three physical mechanisms of weed control: burying, cutting and uprooting. The authors selected cutting, specifically a slicing action, because weeds can be controlled effectively at early growth stages. A shallow operating depth of approximately 10–20 mm was selected to use human power efficiently while limiting the draft requirement. The design calculations considered sustainable human push force, soil resistance, operating angle and cutting width. The study reported maximum two-handed push forces of 498 N for men and 302 N for women, but recommended that repetitive dynamic effort should be limited to about 30% of maximum push force. This consideration contributed to selecting a 250 mm cutting width so the machine could be used by both men and women under the intended operating conditions.

HANDLE DESIGN

Anthropometric measurements were used to determine handle dimensions. Reported elbow heights and hand-related dimensions varied substantially between men and women, so a fixed conventional handle could not provide an equally suitable working position for all operators. The swinging handle was therefore introduced as a practical solution. During operation, the reported handle angles varied approximately from 34–42° during pushing and 38–46° during pulling. The swinging arrangement allowed the handle position to follow the worker's rhythmic movement.

BLADE AND FRAME DESIGN

The cutting blades were arranged at approximately 45° to the line of action and were designed for shallow slicing. Each blade was fabricated from mild steel flat material, with a sharpening edge along its length. The tool bar and shank were designed to withstand bending and torsional loads generated during push-pull operation. A factor of safety of 2 was used in the design calculations. The final machine incorporated two shanks and two weeding blades, with depth adjustment provided through shank height.

SOIL AND OPERATING CONDITIONS

The laboratory soil-bin experiment demonstrated that soil compaction and handle angle influence push force. At the lower compaction level, mean push force remained comparatively low across the tested handle angles. At the higher compaction level, push force increased substantially, particularly at larger handle angles. The study also observed that effective operation in the tested sandy-clay conditions occurred when soil moisture was approximately 8–14% on a dry basis. High weed density could cause clogging, requiring temporary cleaning of the tool. These observations are important because a weeder cannot be evaluated only by its nominal cutting width or machine dimensions. Soil resistance, moisture, weed density, crop geometry and operator movement all affect actual field capacity and draft requirement.

Field Performance of the Manual Four-Wheel Weeder

The prototype was evaluated in maize, spinach, cabbage, okra, capsicum under polyhouse conditions and fallow land. The tested row spacings were mainly 50–60 cm. The reported effective field capacity ranged from 0.0206 to 0.0314 ha/h, depending on crop and field conditions. Weeding efficiency ranged from about 95 to 100%. Walking speed varied from approximately 1.05 to 1.45 km/h. The lowest field capacity occurred in cabbage, while spinach showed the highest reported value among the listed vegetable crops. Variations were attributed to uneven field conditions, crop growth, planting geometry and weed intensity. In some fields the machine had to pass over the same row twice for satisfactory weed removal. In a fallow field with high weed intensity, clogging also reduced the rate of operation.

COMPARISON WITH MANUAL KHURPA WEEDING

For comparison, manual weeding with a khurpa was carried out in okra. The reported effective area covered by the worker was 24.3 m^2/h with 99.8% weeding efficiency. The authors noted that manual workers can also weed within the plant canopy and remove weeds from the field, so the comparison requires care. Even after allowing for this difference, the productivity of the four-wheel machine was reported as more than four to six times that of the conventional method under the studied conditions.

IMPORTANT PERFORMANCE INDICATORS

INDICATOR	MANUAL FOUR-WHEEL WEEDER	OBSERVED RANGE/CONDITION	IMPORTANCE
Field capacity	0.0206–0.0314 ha/h in listed tests	Varied with crop and field	Indicates area covered per unit time
Weeding efficiency	95–100%	Highest when weeds were within blade path	Indicates effectiveness of weed destruction
Push force	155.4 N in fallow field	6.34 N per cm cutting width	Reflects operator workload
Operating speed	1.05–1.45 km/h	Affected by crop geometry and soil	Controls practical field output
Working depth	12–15 mm in field tests	Designed for shallow slicing	Limits draft and crop disturbance

The manual four-wheel weeder therefore demonstrated that ergonomic stability and shallow slicing can provide high weed-control efficiency with a relatively low push-force requirement. However, its output remained constrained by human walking speed and the physical effort needed to propel the machine.

Development of the Battery-Assisted Four-Wheel Weeder

The 2019 study directly extended the earlier four-wheel concept by introducing a battery-powered auxiliary drive. The motivation was to reduce the muscle power required for push-pull operation while increasing working speed and field capacity. The machine retained the four-wheel stability concept and swinging handle but added a brushed DC motor, batteries, a motor speed controller, power transmission, drive wheels and an energy-monitoring system.

POWER SOURCE AND MECHATRONIC SYSTEM

A 250 W, 24 V brushed DC motor was selected. Two 12 V, 14 Ah lead-acid batteries were connected in series to provide the required 24 V supply. A motor speed controller was used to regulate motor speed, while a throttle-position sensor supplied the control signal. The study also developed a digital watt meter using an ATmega328/P microcontroller, an ACS712 current sensor and a voltage sensor to monitor power consumption and battery charging status. The machine used a two-stage power transmission system with an overall reduction ratio of 5.1:1 from the motor to the drive-wheel shaft. The calculated maximum required drive-wheel torque was 51 N·m, while the available maximum tractive torque was 41.42 N·m under the reported traction condition. The draft force corresponding to this tractive torque was approximately 147 N. Beyond this level, the operator had to contribute muscular force to avoid further wheel slippage.

MACHINE CONFIGURATION

The battery-assisted prototype weighed about 30 kg and had a 470 mm wheel base. Its drive wheels measured approximately 406 × 45 mm, while the front wheels measured 254 × 43 mm. The rear wheels were made larger to improve traction and provide an inclined approach for the weeding tool. A 250 mm sweep-type and round-type weeding tool were developed. The tool was positioned toward the front of the machine and mounted so that its width remained sufficiently smaller than the track width to reduce the risk of crop damage.

WHY THE SWEEP TOOL WAS PREFERRED

The assessment of the sweep and round tools showed that the sweep type required lower draft and power and produced higher weeding efficiency. The reported efficiency of the sweep tool was about 98%, whereas the round tool was less effective because weeds could pass or skip sideways. This finding supports the earlier 2016 emphasis on slicing and sweep-type cutting geometry.

Performance of the Battery-Assisted Weeder

The battery-assisted prototype was tested in cauliflower, urd bean, moong bean, maize and pigeonpea. The crop trials used approximately 600 mm row spacing. Walking speed ranged from 2.2 to 3.0 km/h, demonstrating a substantial increase compared with the manual machine. Weeding efficiency ranged from 96.3 to 98.5%, while field efficiency varied from approximately 84 to 92% in the reported crop trials. Across the crop trials, the study reported an average field capacity of 0.0554 ha/h at an average walking speed of 2.52 km/h and an average weeding efficiency of 97.5%. Average draft force and power requirement were approximately 168 N and 153 W, respectively. The authors reported that the battery-assisted machine covered 2.68 times more area than the earlier hand-operated four-wheel weeder, mainly because auxiliary power allowed a higher walking speed and reduced operator workload.

PERFORMANCE IN GRASSY FIELDS AND ORCHARDS

The machine was also tested in an open grassy field and in a farmers' orchard for interculture. In the grassy field, the machine covered 0.0541 ha/h at 2.98 km/h, with 72.13% field efficiency and 97.3% weeding efficiency. In the orchard, it covered 0.0662 ha/h at 2.88 km/h, with 91.94% field efficiency and 98.6% weeding efficiency. Draft and power requirements were higher in the orchard because the reported soil bulk density and working resistance were higher.

BATTERY RUNTIME AND SOLAR CHARGING

Battery performance depended strongly on current demand. The study reported that battery runtime decreased from approximately 420 minutes at 2 A to about 36.18 minutes at 22 A. During weeding, average current demand was approximately 6–7 A, while idle operation consumed about 2–3 A. The authors considered solar charging as a possible renewable-energy option. A 200 W solar panel was estimated to charge a 24 V, 14 Ah battery set in less than three hours under the stated assumptions.

INTEGRATED COMPARISON

PARAMETER	MANUAL FOUR-WHEEL	BATTERY-ASSISTED FOUR-WHEEL
Machine weight	9.5 kg	30 kg
Cutting width	~250 mm	250 mm
Typical speed	~1.05–1.45 km/h	~2.2–3.0 km/h
Weeding efficiency	95–100%	96.3–98.5% in crops; 97.5% average
Power source	Human push-pull effort	24 V battery + 250 W DC motor
Main advantage	Lightweight, ergonomic, low push force	Higher speed, output and reduced drudgery

Discussion and Practical Implications

The two studies represent a clear development pathway. The 2016 machine addressed mechanical and ergonomic problems of conventional wheel weeders by improving stability, depth control and handle adaptability. The 2019 machine retained those design principles and added auxiliary electrical power to overcome the limitation of human propulsion. The progression demonstrates how an agricultural implement can be improved incrementally rather than redesigned completely.

ERGONOMICS AND DRUDGERY REDUCTION

The most important contribution of the manual prototype was the integration of anthropometric data into machine geometry. A suitable handle position, stable four-wheel support and shallow cutting depth reduced the effort associated with maintaining the machine's trajectory and cutting weeds. The battery-assisted version went further by allowing the operator primarily to guide the machine under draft conditions up to the reported traction limit. This is particularly relevant where farm workers have limited physical capacity or where long-duration weeding creates fatigue.

SOIL–MACHINE INTERACTION

The results from both studies show that machine performance is not independent of soil conditions. Increased soil compaction increased push force in the manual machine and increased draft and power demand in the battery-assisted machine. Soil moisture, bulk density, cone index and weed density also influenced field capacity. Therefore, the best performance cannot be expected when the soil is excessively hard, very dry or heavily infested with weeds.

CROP GEOMETRY AND CROP SAFETY

Wide-row compatibility was a major design target. The 2016 machine was intended for rows of approximately 300 mm and above, while the battery-assisted prototype was tested particularly in 600 mm row spacing. The placement of the weeding tool in front of the machine and the restriction of tool width relative to track width were intended to reduce crop injury. However, the source studies also indicate that crop geometry and canopy development can reduce working speed, especially in mature crops and rotected cultivation.

ADVANTAGES AND LIMITATIONS

Advantages of the manual machine: low weight, simple construction, no battery requirement, good weeding efficiency, four-wheel stability and ergonomic swinging handle. Advantages of the battery-assisted machine: higher walking speed, greater field capacity, high weeding efficiency, reduced operator workload and potential for solar-assisted charging. Limitations of the manual machine: output is constrained by human propulsion, and high weed density or hard soil can increase effort and clogging. Limitations of the battery-assisted machine: greater machine weight, dependence on battery charge, higher system complexity and possible wheel slippage when draft exceeds the reported traction limit.

Suggestions for Future Development

Based strictly on the limitations and performance patterns reported in the two source articles, future development should focus on improving battery endurance, reducing machine mass, optimizing traction and making the tool system more adaptable to different row spacings. A modular blade system could allow rapid change of cutting tools, while improved energy storage and solar charging could support longer operation. More extensive testing under different soil textures, moisture conditions, weed species and farm sizes would also help establish broader adoption potential.

Conclusion

The two studies collectively demonstrate the development of a wide-row mechanical weeding system from a lightweight ergonomic implement to a battery-assisted machine. The 2016 four-wheel weeder addressed the major limitations of conventional wheel weeders through four-wheel stability, a swinging handle, shallow slicing action and anthropometric design. It achieved 95–100% weeding efficiency in the reported tests while maintaining a machine weight of 9.5 kg. The 2019 battery-assisted version incorporated a 250 W DC motor and 24 V battery system, increasing operating speed and field capacity while retaining high weed-control efficiency. The battery-assisted machine achieved an average field capacity of 0.0554 ha/h at 2.52 km/h with 97.5% weeding efficiency, compared with the lower operating speeds and capacities of the manual machine. The evidence indicates that auxiliary power can substantially increase output by reducing the physical workload required from the operator. At the same time, traction, draft, soil compaction, weed density and battery runtime remain important constraints. The combined findings support the use of four-wheel, ergonomically designed and electrically assisted weeders as promising tools for wide-row crops, particularly where reduction of manual drudgery and improvement of field productivity are priorities.

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