Design, Development and Analytical Assessment of a Low-Cost Multipurpose Agricultural Fixture for Simultaneous Weed Control and Pesticide Application in Smallholder Farming

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Abstract

Smallholder farmers in developing countries face persistent challenges in weed management and pesticide application because of labour shortages, increasing operational costs, and occupational exposure to agrochemicals. This study presents the design and analytical assessment of a low-cost multipurpose agricultural fixture mounted on a conventional two-wheeler platform to combine inter-row weed cutting and pesticide spraying in a single pass. The prototype incorporates a mild-steel structural frame, three adjustable weed-cutting blades, a 60-L polyethylene tank, a 12-V battery-operated pump, delivery lines, and adjustable hollow-cone nozzles. A SolidWorks model was developed considering crop-row spacing, crop height, vehicle geometry, and operator accessibility. Preliminary draft force and power requirements were estimated using the modified ASABE Universal Draft Equation; the estimated draft force was 3177.59 N and the corresponding power requirement was 1.32–2.65 kW over an operating-speed range of 1.5–3 km h−1. Importantly, these values are analytical design estimates and were not experimentally validated using a drawbar dynamometer, load cell, torque measurement, or wheel-slip instrumentation in the present study. Prototype operation was assessed qualitatively for integrated blade engagement and spraying functionality, but quantitative measurements of weeding efficiency, spray deposition, crop damage, traction, structural response, and energy consumption were not undertaken. Accordingly, the present work establishes a preliminary design and feasibility framework rather than a fully field-validated performance claim.

Keywords: Agricultural mechanization, Weed management, Pesticide spraying, Farm machinery, Smallholder farming, Multipurpose agricultural fixture, Sustainable agriculture.

1. Introduction

Agriculture remains one of the most important sectors supporting rural livelihoods and economic development in many developing nations. However, small and marginal farmers continue to rely heavily on manual labor and animal-powered operations for crop production [1]. Weed management and pesticide application are among the most labor-intensive activities and significantly influence crop productivity. Inefficient weed control reduces nutrient availability, water utilization efficiency, and crop yield, while improper pesticide application exposes farmers to serious health risks.

Several researchers have proposed mechanized agricultural devices including weeders, pesticide sprayers, multi-utility agricultural vehicles, and autonomous agricultural robots. Nevertheless, most available systems perform only a single agricultural operation or involve high capital investment, limiting their adoption by smallholder farmers [2]. A critical gap exists in the development of affordable equipment capable of performing multiple agricultural operations simultaneously.

The objective of the present work is to design and develop a multipurpose agricultural fixture capable of simultaneously performing weed cutting and pesticide spraying. The fixture is designed to be mounted on a conventional two-wheeler vehicle, thereby utilizing existing farm resources and minimizing implementation costs.

Although the integrated concept addresses a practical mechanization need, a two-wheeler-mounted implement cannot be considered fully validated from analytical power calculations alone. Its engineering performance also depends on drawbar traction, wheel slip, structural loading, payload-induced centre-of-gravity changes, spray delivery characteristics, and crop–implement interaction. The present study therefore distinguishes analytical feasibility from experimentally validated field performance. In addition, the low-cost claim requires quantitative cost accounting and benchmarking against comparable equipment rather than a qualitative statement alone.

1.1 Objectives of the work

The primary objective of this study is to design and develop a low-cost multipurpose agricultural fixture that integrates inter-row weed cutting and pesticide spraying on a conventional two-wheeler platform. Specific objectives are to: (i) develop an adjustable fixture compatible with crop-row spacings of 254–356 mm and crop heights up to 250 mm; (ii) estimate the preliminary draft-force and power requirements using an established agricultural-implement draft formulation; (iii) assess the prototype qualitatively for simultaneous blade engagement and spraying functionality; (iv) evaluate the economic feasibility using commercially available components and an existing vehicle platform; and (v) identify the structural, traction, spray, agronomic, and safety measurements required for rigorous experimental validation. The analytical calculations are therefore treated as preliminary design estimates and not as substitutes for field measurements.

2. Literature Review

The literature indicates extensive efforts toward agricultural mechanization, including ploughing machines, multi-utility agricultural vehicles, power weeders, robotic agricultural systems, and multi-nozzle pesticide sprayers [3]. However, existing systems primarily focus on individual operations such as ploughing, sowing, or spraying. Very limited research has addressed simultaneous weed removal and pesticide application within a single compact fixture suitable for small farms [4].

The review establishes the need for an integrated and economically feasible solution capable of improving operational efficiency while reducing labor requirements and pesticide exposure.

3. Design Requirements

The design and development of the proposed low-cost multipurpose agricultural fixture were guided by the practical needs of smallholder farmers, with emphasis on affordability, functionality, and operational efficiency. The primary design considerations included minimizing manufacturing cost by utilizing readily available materials and simple fabrication techniques, thereby ensuring economic feasibility for resource-constrained users. To maximize adaptability, the fixture was designed to be compatible with conventional two-wheelers commonly used in rural areas, eliminating the need for dedicated agricultural machinery. An adjustable row-spacing mechanism was incorporated to accommodate a variety of crop geometries and field conditions, thereby enhancing its versatility. The system integrates simultaneous weed-cutting and pesticide-spraying operations into a single pass, significantly reducing labour requirements, operational time, and overall field management costs. Furthermore, the fixture was engineered for ease of operation and maintenance, enabling farmers with minimal technical expertise to operate and service the equipment effectively. Particular attention was also given to reducing power consumption through an efficient mechanical design, ensuring reliable performance while minimizing fuel usage and operating expenses. These design considerations collectively contribute to the development of a cost-effective, user-friendly, and efficient agricultural implement capable of improving productivity and sustainability in smallholder farming systems.

The design requirements also include vehicle integration and safety. The fixture has a reported mass of approximately 52 kg and is intended to carry a 60-L tank; therefore, the full payload can influence axle loading, centre of gravity, braking response and directional stability. These factors were considered at the design level, but quantitative axle-load, braking, rollover-margin, dynamic-load and structural analyses were not performed in the present study and are treated as validation requirements.

3.1 CAD Modelling

The fixture was designed using SolidWorks software. The detailed description of each components are explained in the following section.

Frame

A mild-steel angle frame was selected due to its strength, availability, and cost-effectiveness.

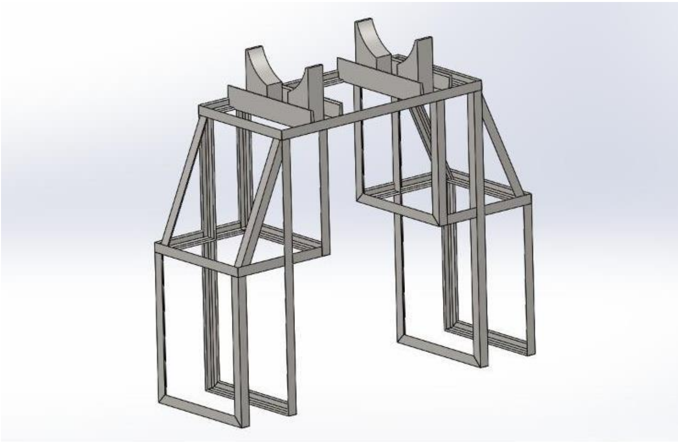

Fig.1 Frame

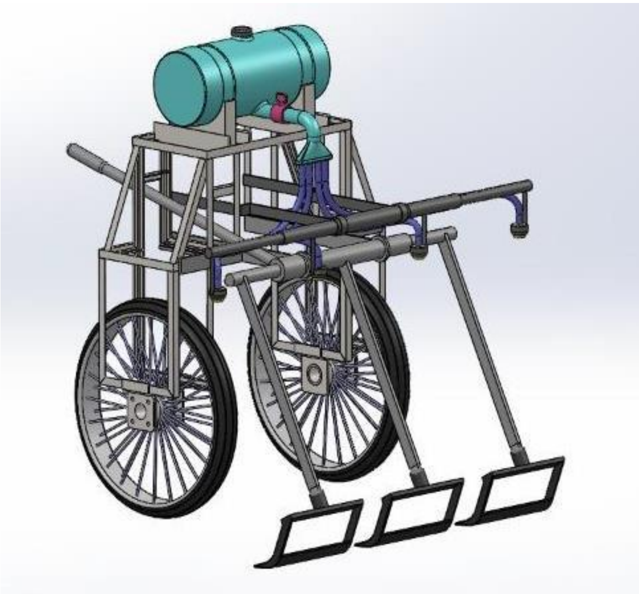

Fig.2: 3D model

Spraying System

The spraying subsystem includes a 60-L polyethylene tank, 12-V battery-operated pump, delivery lines, and adjustable hollow-cone nozzles. The available design record does not specify the pump discharge rate, operating pressure, battery capacity/runtime, nozzle droplet-size distribution, or experimentally measured application rate. Consequently, these are reported as design features rather than measured performance parameters. Quantitative spray characterization should include pump flow rate, nozzle pressure and flow, spray width, application rate, droplet-size distribution, deposition uniformity, and battery operating duration.

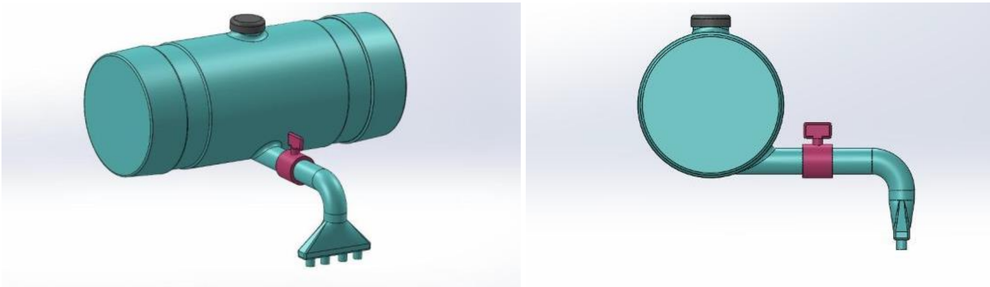

Fig.3: Tank and nozzle

Weed-Cutting System

Three adjustable blades are positioned between crop rows. A manually actuated lever mechanism allows engagement and disengagement of the blades according to field requirements. The present study does not report direct measurements of blade cutting force, weed-control efficiency, weed density before and after operation, or crop injury. Because inter-row weed cutting involves blade–soil–weed interaction rather than conventional bulk tillage alone, future validation should include blade-specific cutting/shearing measurements under controlled soil and weed conditions.

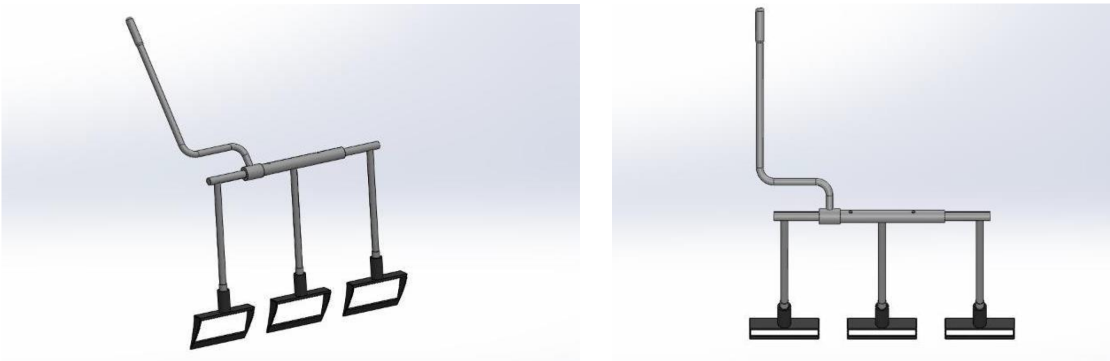

Fig.4: Weed cutting Blades

4. Analytical Design and Power Estimation

The preliminary draft force acting on the weed-cutting assembly was estimated using the modified ASABE Universal Draft Equation:

$$D = F[A + BS + CS^2]WT + K_2$$

where D represents draft force, F is the soil-related factor used in the selected formulation, S is forward speed, W is working width, T is tillage depth, and A, B and C are implement-specific coefficients. The original design record does not identify, with sufficient reproducibility, the exact Table 1 coefficient row, numerical values of F and T, or the complete numerical substitution leading to 3177.59 N. Accordingly, the reported value is treated as a preliminary analytical estimate rather than an experimentally validated weed-cutting force.

The calculated draft force was approximately 3177.59 N. Because the source calculation does not preserve the complete coefficient selection and numerical substitution, the revised manuscript does not retrospectively assign an unverified implement category, soil factor, or tillage depth. The final experimental study should report the selected Table 1 row, all factors and coefficients, assumed operating depth and soil condition, unit conversions, and complete numerical substitution so that the calculation can be independently reproduced.

Table: Soil and machine parameters

Implement	Width Units	A	B	C	F_1	F_2	F_3	Range ± %
Mold Board Plough	m	652	0.0	5.1	1.0	0.70	0.45	40
Offset Disc Harrow (Primary Tillage)	m	364	18.8	0.0	1.0	0.88	0.78	50
Cultivator (Secondary Tillage)	m	254	13.2	0.0	1.0	0.88	0.78	30
Cultivator (Primary Tillage)	No.	46	2.8	0.0	1.0	0.85	0.65	30
Cultivator (Secondary Tillage)	No.	32	1.9	0.0	1.0	0.85	0.65	25

Application of a tillage-based draft equation to inter-row weed cutting is a preliminary engineering approximation. The equation represents implement draft through empirical agricultural-implement coefficients and does not explicitly resolve blade geometry, soil shear, soil moisture, soil cohesion, weed-root resistance, or local soil disturbance. A blade-specific cutting-force/shear model supported by load-cell measurements under representative soil and weed conditions is therefore required before the draft force can be considered a validated performance parameter.

The power requirement was determined as:

$P = D \times V$

The estimated power demand ranged from:

- 1.32 kW at 1.5 km h^{-1}
- 2.65 kW at 3 km h^{-1}

These values provide a first-order power-feasibility assessment only. No direct measurement of engine torque, drawbar force, wheel torque, fuel consumption, or wheel slip was performed. Thus, suitability of a conventional two-wheeler should be interpreted as preliminary power compatibility rather than experimentally verified tractive adequacy or controllability. Field validation should measure drawbar force, wheel slip ratio, vehicle speed, axle loads and engine/drive torque across representative soil conditions.

5. Results and Discussion

The prototype was examined at the design level and through qualitative operation of the integrated mechanism. The fixture accommodates adjustable crop-row spacings of 254–356 mm and was configured for crop heights up to approximately 250 mm. The operating-speed range considered in the analytical assessment was 1.5–3 km h^{-1}. Prototype operation indicates that the inter-row blades and spraying subsystem can be integrated within a compact two-wheeler-mounted architecture. However, the present study did not generate sufficient quantitative field data to claim measured weed-control efficiency, spray uniformity, crop-safety performance, traction adequacy, or field productivity. These observations were not supported by replicated measurements, uncertainty analysis, or statistical treatment.

The fixture has a self-weight of approximately 52 kg and is designed to carry a 60-L tank. When the tank is full, the payload introduces a substantial additional load relative to the fixture mass. The present study did not perform finite-element stress/deflection analysis, axle-load measurement, braking tests, or dynamic-load testing. Consequently, structural integrity and vehicle stability cannot be claimed as experimentally demonstrated. A complete validation program should model the combined fixture mass, full-tank load, estimated draft reaction, mounting reactions and dynamic load factor, and should verify stresses, deflections, fastener loads and safety factors experimentally at critical locations.

5.2 Traction and controllability

The estimated 3177.59 N draft force was not verified through drawbar testing. Transmission of the draft reaction to the soil through the vehicle tyres depends on axle loading, tyre–soil friction, soil moisture, tyre condition and speed. Consequently, wheel traction and slip should be experimentally quantified before unrestricted field deployment. The present results establish only an analytical power requirement and not a demonstrated 3177 N drawbar capability.

5.3 Spraying performance

The spraying subsystem was designed around a 60-L tank, a 12-V pump and adjustable hollow-cone nozzles. Quantitative pump flow rate, nozzle pressure, application rate, droplet-size distribution, battery runtime and deposition uniformity were not measured in the present study. Accordingly, pesticide application is treated as a functional design capability rather than a measured uniformity result. Future evaluation should use calibrated flow measurements and water-sensitive papers or equivalent collectors to determine spray deposition, coverage and application-rate uniformity.

5.4 Weeding effectiveness and crop damage

No replicated measurements of weed density before and after operation, weed-control efficiency, blade cutting efficiency, or crop injury were recorded. Weed removal is therefore treated as a qualitative prototype observation. A rigorous field protocol should report weed density, weed-control efficiency, crop stand/damage, working width, forward speed, effective field capacity and repeated-trial variability for each operating condition.

5.5 Quantitative benchmarking

The literature review identifies weeders, agricultural vehicles, robots and multi-nozzle sprayers, but the available source material does not provide a sufficiently consistent numerical dataset for a defensible performance ranking. The proposed fixture should be benchmarked against representative commercial and published systems using common indicators: draft force, power, operating speed, field capacity, weed-control efficiency, spray deposition/coverage, labour requirement, fuel or energy consumption, acquisition cost and number of operations completed per pass.

6 Structural and vehicle-load assessment - Economic Analysis

The proposed fixture is intended as a low-cost concept because it uses a conventional two-wheeler platform and commercially available components. However, the present manuscript does not contain a complete itemized bill of materials or verified current market prices. Therefore, “low-cost” is treated as a design objective rather than a quantitatively established comparative result. A rigorous economic assessment should report the costs of the mild-steel frame, blades, tank, pump, battery, nozzles, piping, fasteners, fabrication and assembly separately, and should compare the resulting total with relevant commercial weeders, sprayers and multipurpose implements using equivalent capacity and functionality. Operating cost should additionally account for labour, fuel/energy, maintenance and the number of field passes required.6.1 Safety and ergonomic considerations The 60-L tank and fixture mass can alter vehicle centre of gravity, axle loading, braking response and directional stability. The present study identifies these as design constraints but does not report quantitative stability testing. For field deployment, the tank should be rigidly secured and positioned as low as practicable; hoses and electrical lines should be protected from moving components; chemical handling should follow applicable pesticide-safety requirements; and the mounting structure should be checked for static and dynamic loads. Future testing should quantify centre-of-gravity shift, axle loads, braking distance, lateral stability and mounting integrity with empty and full tank conditions.

7. Conclusions

The present study developed and analytically assessed a low-cost multipurpose agricultural fixture intended to combine inter-row weed cutting and pesticide spraying on a conventional two-wheeler. The design incorporates a 52-kg mild-steel fixture, a 60-L tank, three adjustable cutting blades, a 12-V pump and adjustable hollow-cone nozzles, with crop-row spacing adjustable over 254–356 mm. A modified ASABE Universal Draft Equation was used as a preliminary design tool, giving an estimated draft force of 3177.59 N and a corresponding analytical power requirement of 1.32–2.65 kW over 1.5–3 km h−1. These values have not been experimentally validated and should therefore be interpreted as preliminary estimates.

Prototype-level operation indicates that simultaneous blade engagement and spraying can be integrated within a compact two-wheeler-mounted architecture. Nevertheless, the present evidence does not establish quantitative weeding efficiency, spray deposition uniformity, crop damage, traction/slip performance, structural safety, or comparative economic superiority. In addition, the use of a tillage-based draft formulation for weed cutting is an approximation because the actual blade–soil–weed interaction is not explicitly represented. Future work should include direct draft-force measurement, wheel-slip and axle-load testing, finite-element and experimental structural validation, calibrated spray characterization, replicated field trials for weed-control efficiency and crop damage, itemized cost benchmarking, and development of a blade-specific soil shear/cutting-force model across different soil conditions.

8. Study Limitations and Validation Requirements

The principal limitation of the present study is that the available experimental record does not contain the quantitative field measurements required to validate the analytical draft-force/power estimate or the claimed agronomic and safety performance. In particular, the exact coefficient set and numerical assumptions used to obtain 3177.59 N are not fully recoverable from the current design record; direct draft, traction, structural, spray and agronomic measurements were not performed; and a complete bill of materials and market benchmark were not available. These limitations are explicitly reflected in the revised interpretation of the results. The manuscript therefore avoids presenting unmeasured quantities as experimentally established outcomes and defines a reproducible validation program for future work.

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