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Pendram Kavya
College of Agricultural
Engineering, Department of
Farm Machinery and Power
Engineering, CAE, PJTAU,
Kandi, Sangareddy,
Telangana, India

Dr. Satyanarayan
Assistant Professor & Head,
Department of Farm
Machinery and Power
Engineering, CAE, PJTAU,
Kandi, Sangareddy,
Telangana, India

S Dinesh
College of Agricultural
Engineering, Department of
Farm Machinery and Power
Engineering, CAE, PJTAU,
Kandi, Sangareddy,
Telangana, India

R Srikanth
College of Agricultural
Engineering, Department of
Farm Machinery and Power
Engineering, CAE, PJTAU,
Kandi, Sangareddy,
Telangana, India

B Veerabadram
College of Agricultural
Engineering, Department of
Farm Machinery and Power
Engineering, CAE, PJTAU,
Kandi, Sangareddy,
Telangana, India

Valle Navya
College of Agricultural
Engineering, Department of
Farm Machinery and Power
Engineering, CAE, PJTAU,
Kandi, Sangareddy,
Telangana, India

Corresponding Author:
Pendram Kavya
College of Agricultural
Engineering, Department of
Farm Machinery and Power
Engineering, CAE, PJTAU,
Kandi, Sangareddy,
Telangana, India

Development of multipurpose tool carrier for sowing and spraying operations for field crops

Pendram Kavya, Satyanarayan, S Dinesh, R Srikanth, B Veerabadram and Valle Navya

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Abstract

The multipurpose tool carrier (MPTC) was developed to integrate sowing and spraying functionalities, addressing inefficiencies in traditional farming practices. Designed with a robust frame, modular attachments, and adjustable nozzles, the MPTC features a 16-liter pesticide tank and a precision seed metering mechanism. Laboratory and field evaluations demonstrated its superior performance. The spraying attachment achieved a discharge rate of 1263.25 ml/min and a field efficiency of 80.98%, outperforming knapsack sprayers. The sowing attachment exhibited 98.86% seed uniformity and 93.91% field efficiency, with minimal seed damage (3%). The MPTC covers four rows simultaneously, reducing labour and operational time. Its modular design ensures versatility and ease of maintenance, making it a cost-effective solution for small and marginal farmers. This innovation enhances agricultural productivity and sustainability, with future work focusing on optimizing the design for diverse crops and field conditions.

Keywords: Multi-purpose tool carrier, knapsack sprayer, field efficiency, seed uniformity

1. Introduction

In India, where agriculture is a cornerstone of the economy, employing a significant portion of the workforce, particularly small and marginal farmers, enhancing agricultural productivity is paramount (Government of India, 2023). Agriculture is the backbone of global food security, and the adoption of advanced machinery is critical to meet the growing demand for food (FAO, 2021). Traditional farming methods often demand substantial manual effort, leading to inefficiencies and potential health issues (Singh & Singh, 2019) [14]. To mitigate these challenges, the development of multipurpose tool carriers (MPTCs) has emerged as a viable solution for small and medium-sized farms (Kumar & Pandey, 2020) [15]. MPTCs are engineered to execute various agricultural tasks, including seed planting, fertilizing, spraying, and inter-cultivation, utilizing a single frame with interchangeable attachments (Yadav & Khurana, 2021) [15].

Pesticide spraying is a critical operation in agriculture, essential for protecting crops from pests and diseases (FAO, 2020). However, the traditional methods of carrying and operating spraying equipment often lead to physical strain, particularly shoulder pain, due to the manual handling of heavy pumps (Mehta & Chandel, 2018) [10]. This challenge is especially pronounced in regions where farmers rely heavily on manual labor, leading to inefficiencies and health issues over time (Narayanamoorthy, 2017) [11].

Sowing is one of the most important operations in crop production, which requires precise placement of seed with set seed rate to maximize crop yield (Kachman & Smith, 1995) [7]. Uniformity in seed dropping in rows depends on the planter seed metering rotor performance (Karayel, *et.al*, 2006) [8]. The assessment of plant spacing and seed rate as provided by the planters is also crucial in analysing their performance (ASABE Standards, 2020).

Conventional sprayers having the difficulties such as it needs lot of effort to crank lever up and down in order to create the pressure to spray the pesticide (Patel & Tiwari, 2019) [12]. Sprayer can also be operated using battery driven or engine operated and ground wheel driven also in order to overcome the problems of farmers in purchase of fuel which increases the running cost of the operation (Kumar & Singh, 2020) [6]. Hence wheel driven

Multipurpose Tool carrier need to be designed consisting of sowing attachment and sowing operations for field crops like cotton, red gram etc (Yadav & Khurana, 2021)^[15].

The fabrication of the machine will be done as per the detailed drawing of the machine (Srivastava, *et al.*, 2006)^[13]. Developed machine will be optimized in the laboratory for effective performance while sowing and spraying operation by selecting performance parameters for determination (Liu, J *et al.* (2016)^[9] After laboratory testing of the equipment, further it will be modified as per the requirement which suits to actual field condition will also be evaluated and demonstrated at farmer's field (Kumar & Pandey, 2020)^[5].

The development of a multipurpose tool carrier (MPTC) for sowing and spraying addresses the inefficiencies and physical strain of traditional farming methods. By integrating multiple operations into a single machine, it reduces labor, time, and costs while improving precision and productivity, particularly benefiting small and marginal farmers in India.

Objectives

1. Development of Multipurpose tool carrier consisting of Sowing equipment and Sprayer.
2. Performance evaluation of developed Equipment under laboratory condition to optimize the performance parameters.
3. Performance evaluation of developed equipment in field condition.

2. Materials and Methodology

The methods followed for the development of different components required for multipurpose tool carrier consisting of sowing and spraying attachment and other details required for the development of multipurpose tool carrier to suit selected field crops were also narrated. The evaluation techniques used to find the performance of the machine for the field conditions for the selected field crops were enumerated under the following sub heading.

2.1 Components and Attachments

1. **Main Frame:** The base structure supporting all attachments, constructed from durable materials to ensure stability and strength.
2. **Spraying Attachment:** A pesticide sprayer designed to minimize manual effort and reduce shoulder pain during operation.
3. **Sowing Mechanism:** A precision seed placement device for efficient sowing in ploughed fields.

2.1.1 Development of Multipurpose Tool Carrier (MPTC)

The multipurpose tool carrier integrates sowing and spraying functionalities, powered by a ground wheel and battery.

Features

- A separate frame for mounting the spray tank and seed hopper.
- A front-mounted ground wheel for ease of operation.
- Adjustable settings for boom/nozzle height, single seed placement, and seed spacing.

2.1.2 Design and Fabrication

1. Frame Construction

- The frame is made from two long, 3mm thick, 20mm diameter rods, bent and welded into an ergonomic handle.
- A supporting frame at the handle's end secures the main equipment body.
- A stand is provided below the frame to reduce operator fatigue during rest.

2. Front-Mounted Wheel

- A 480mm diameter wheel is connected to the equipment via sprockets and chains.
- This wheel drives the sowing or spraying mechanisms, ensuring smooth operation.

3. Spraying Attachment

- A nozzle-equipped tube is fixed to a boom attached to the sprayer.
- The boom is connected to the frame for stable and directed pesticide application.
- A handle-mounted lever controls the spraying action, providing precise control.

4. Modularity

- Attachments are designed for easy dismantling, allowing quick switching between sowing and spraying tasks.
- This modularity simplifies maintenance and enhances the tool's adaptability.

2.2 Fabrication of Single Wheel-Driven Boom Sprayer

1. Body of the Sprayer

- Constructed from a 25mm diameter hollow circular rod.
- Includes a pesticide tank, on-off valve, wheel with gear mechanism, and a boom set with four nozzles.
- The tank and wheel are strategically placed, with the gear mechanism enabling spray control.



Fig 1: Body of sprayer



Fig 2: Handle

Handle

- Designed in a 'Z' shape for both pushing and pulling motions.
- Made from 25mm diameter hollow circular rods, 720mm long, and positioned 460mm above the ground.

2.2.1 Functional Parts of sprayer

1. Pesticide Tank

- A 16-liter tank with dimensions 340×190mm is mounted on a frame stand.
- Positioned 110mm away from the handle end for balance.



Fig 3: Pesticide tank

2. Wheel and Gear Connection

- A 480mm diameter wheel is connected to a gear system (39-tooth and 13-tooth gears) with a 3:1 speed ratio.
- The gear mechanism converts rotary motion into reciprocating motion for the piston.



Fig 4: Wheel and gear connection

3. On-Off Valve

Controls the flow of pesticide, preventing wastage during transport or idle periods.

4. Boom Set

- A 1-meter-long boom with four nozzles is attached to the sprayer.
- Adjustable in height and angle for versatile application.

5. Nozzles

Three types of nozzles are used

- **Hollow-Cone Nozzle (N₁):** For insecticides and fungicides, providing complete leaf coverage.
- **Solid-Cone Nozzle (N₂):** Covers a small area with uniform spray.
- **Flat-Fan Nozzle (N₃):** Ideal for low-pressure spraying, creating a narrow elliptical spray pattern.



Fig 5: Nozzles

2.3 Constructional Details of Seeding Attachment

1. Main Frame

Made from mild steel angle bars (70cm long, 2mm thick) for rigidity and durability.

2. Adjustable Handles

Constructed from mild steel flat bars (895mm long) with a 20mm external diameter pipe for grip.

3. Seed Hopper

Made of mild steel with a frustum cross-section (20×20cm) to hold seeds.



Fig 6: Seed Hopper

4. Seed Metering Mechanism

- A nylon metering wheel with cells on its periphery ensures uniform seed distribution.
- The number of cells is calculated based on seed size and desired spacing.



Fig 6: Metering mechanism

5. Adjustable Furrow Opener

A pointed bar-type opener made of mild steel for creating narrow slits in the soil.



Fig 7: Furrow opener

6. Seed Tube

A 15mm diameter rubber hose pipe (500mm long) guides seeds from the hopper to the furrow.

7. Furrow Covering Device

A rectangular mild steel plate (230×30mm) covers the seeds after placement.



Fig 9: Covering device

8. Chain and Sprocket

Power is transmitted from the front wheel to the seed metering mechanism via a chain and sprocket system (18-tooth and 48-tooth sprockets).



Fig 10: Chain and sprocket arrangement for seed metering mechanism



Fig 11: Multi-purpose tool carrier with seed showing and spraying mechanism

2.4 Performance Evaluation of Developed Equipment Under Laboratory Conditions

The performance of the developed multipurpose tool carrier (MPTC) was evaluated under laboratory conditions to optimize its operational parameters. The evaluation focused on both the sowing and spraying equipment, ensuring their efficiency and precision in field applications.

2.4.1 Determination of Biometric Parameters for Sowing

The biometric parameters of selected seeds were determined to optimize the sowing equipment. These parameters included:

- Type of Crop: Selected based on regional agricultural practices.
- Physical Dimensions: Length, width, thickness, and sphericity of seeds were measured.
- Bulk Density: Calculated to determine the seed hopper capacity.
- Moisture Content: Measured to ensure seed quality and germination rate.

2.5 Performance Evaluation of Sowing Equipment

1. Seed Rate

- The number of seeds dropped by the metering mechanism was manually counted at the recommended forward speed.
- The equipment was calibrated under laboratory conditions to ensure accurate seed delivery at different speeds.

2. Seed-to-Seed Distance

- An artificial sand bed (25 cm deep, 5 meters long) was prepared to simulate field conditions.
- The sowing equipment was operated over the bed, and the number of seeds dropped and the average distance between seeds were recorded.
- The test was repeated twice to ensure consistency.

2.6 Performance Evaluation of Spraying Equipment

1. Discharge Rate

- The discharge rate of the sprayer was measured at three operating pressures.
- Three types of nozzles (hollow cone, solid cone, and flat fan) were tested, and the discharge from each nozzle was collected and averaged.
- Field discharge rates were also determined by operating the sprayer for one hour at different forward speeds.

2. Spray Uniformity

- Spray uniformity was assessed using a spray patternator.
- The nozzle was positioned 500 mm above the patternator, and the spray liquid collected in the channels was measured.
- The coefficient of uniformity (Cu) was calculated using the formula:

$$cu = \left(1 - \frac{\sum x}{mn}\right) \times 100$$

Where,

C_u = coefficient of uniformity, percent

X = absolute numerical deviations of the individual observations from the average application, mm

m = average of all observations, mm

n = total number of the observations

2.7 Performance Evaluation of multipurpose tool carrier in Field Conditions

The MPTC was tested in field conditions to assess its practical performance for field crops.

1. Chemical Application Rate

The spraying equipment's chemical application rate was measured to ensure precise pesticide delivery.

2. Field Capacity

The operational efficiency of the MPTC was evaluated by measuring the area covered per unit time.

3. Uniformity of Seed Placement

- The uniformity of seed placement was assessed by measuring the distance between seeds in the field.
- The results were compared with laboratory findings to validate the equipment's performance.

2.7.1 Calibration and Evaluation of Single Wheel-Driven Boom Sprayer

1. Total Spray Output (L/min)

- Fill the spray tank with water and place a measuring jug under one nozzle.
- Run the sprayer for one minute and measure the collected water.
- Repeat for all nozzles and sum the measurements to determine total spray output.

2. Travel Speed (km/h)

- Measure a 100-meter distance and record the time taken to cover it.
- Calculate speed using:

$$\text{Travel speed (km/h)} = \frac{100 \text{ (m)} \times 3.6}{\text{time (seconds)}}$$

3. Spray Application Rate (L/ha)

- Measure swath width (nozzle spacing × number of nozzles).
- Calculate application rate using:

$$\text{Application rate (L/ha)} = \frac{600 \times \text{total sprayer output} \left(\frac{\text{L}}{\text{min}}\right)}{\text{swath width (m)} \times \text{travel speed} \left(\frac{\text{km}}{\text{h}}\right)}$$

4. Nozzle Angle

Measure swath width (b) and boom height (h).

Calculate nozzle angle (θ) using: $2 \tan^{-1} b/2$.

h - Height of boom from ground level during operation

b - Swath width of the disc head

θ - Nozzle Angle.

5. Field Capacity

- Theoretical Field Capacity (ha/h):

$$= \frac{\text{width (m)} \times \text{speed} \left(\frac{\text{m}}{\text{h}}\right)}{10000}$$

- Field Efficiency (%): $= \frac{\text{Effective field capacity}}{\text{theoretical field capacity}} \times 100$

- Effective field capacity (ha/h): Actual area covered based on its total time and its width

2.7.2 Evaluation of Knapsack Sprayer

1. Area Rate

- Spray a test plot and record the time taken.
- Calculate area rate using:

$$\text{Area of test plot} = \text{length} \times \text{breadth (m}^2\text{)}$$

$$\text{Area rate of sprayer} = \frac{\text{Area of test plot (ha)}}{\text{time taken (h)}}$$

2. Volume Rate

- Measure discharge from a nozzle using a beaker.
- Calculate volume rate using:

$$\text{Volume rate} = (\text{volume collected (L)}) / (\text{Time (h)})$$

$$\text{Application Rate} : \frac{\text{volume rate (L)}}{\text{Area rate (ha)}}$$

2.8 Sowing Attachment Testing

- Physical Properties of Seeds: Measure size, sphericity, bulk density, and angle of repose.
- Seed Emergence Factors: Ensure uniform seed depth, distribution, and prevention of soil displacement.

3. Result and discussion

3.1 Performance Evaluation of developed Equipment under Laboratory condition to optimize the performance parameters

3.1 Experimental procedure

3.1.1 Calibration of Spraying Attachment

A test plot of 4 m² was used to calibrate the spraying attachment. The following observations were recorded:

- Sprayer Rate: 0.072 ha/h
- Volume Rate of Knapsack Sprayer: 34.56 L/h
- Application Rate of Knapsack Sprayer: 480 L/ha

3.2 Performance of Single Wheel-Driven Boom Sprayer Calibration of Spraying Attachment

The spraying attachment was calibrated using a 4 m² test plot, yielding a sprayer rate of 0.072 ha/h and a volume rate of 34.56 L/h.

3.3 Performance of Single Wheel-Driven Boom Sprayer

- The total sprayer output was measured at 1263.25 ml/min, with consistent discharge across all four nozzles.
- This high discharge rate ensures faster and more efficient coverage compared to the knapsack sprayer's 0.576 L/min, reducing the time required for spraying operations.

Travel Speed

- The average travel speed of the boom sprayer was 3.25 km/h, the average travel speed of time was 110.53 sec.
- Despite the lower speed, the boom sprayer's ability to cover four rows simultaneously compensates for this, enhancing overall operational efficiency.

3.4 Nozzle Adjustment Angle

The nozzle adjustment angle was optimized at a boom height of 46 cm, with an angle of 112.41°. Nozzles with spray fan angles less than 110° minimize drift at heights above 0.5 m (P.C.H. Miller, 2004), ensuring precise and uniform pesticide application.

Field Capacity

- The theoretical and effective field capacities were 0.08125 ha/h and 0.0658 ha/h, respectively, with a field efficiency of 80.98%.
- This efficiency is higher than the knapsack sprayer's 0.072 ha/h, demonstrating the boom sprayer's superior performance in covering larger areas in less time.

3.5 Spray Overlap

- Spray overlap varied with boom height and nozzle spacing, with a maximum overlap of 111.1% at a height of 118 cm and nozzle spacing of 45 cm.
- This ensures uniform pesticide application, reducing the risk of under or over-spraying.

3.6 Performance Evaluation of Sowing attachment

• Calibration of Seed Drill

The seed drill was calibrated as per IS: 6316:1993, with 145 seeds discharged after 45 revolutions of the drive wheel, confirming the accuracy of the seed metering mechanism.

• Mechanical Damage

The mechanical damage to seeds during calibration was 3%, which is within acceptable limits for most crops.

• Seed Distribution Test

After 20 revolutions of the drive wheel, the average seed discharge from the furrow opener for Unit 1, Unit 2, and Unit 3 was 175, 230, and 335 seeds, respectively.

• Seed Uniformity Test

1. The 4 mm hole size metering device achieved a coefficient of uniformity of 98.86%, significantly higher than the 3 mm hole size device (76.92%).
2. The average spacing between seeds for the 4 mm device was 14.83 cm, compared to 19.50 cm for the 3 mm device.

• Field Performance

1. The theoretical field capacities for Unit 1, Unit 2, and Unit 3 were 0.147, 0.153, and 0.147 ha/h, respectively.
 2. The actual field capacities were 0.137, 0.147, and 0.137 ha/h, respectively.
 3. The average field efficiency was 93.91%, indicating high operational efficiency.
- The 4 mm hole size metering device demonstrated superior performance in terms of seed uniformity and spacing, making it more suitable for precision sowing.
 - The low mechanical damage rate (3%) ensures minimal seed loss, contributing to higher crop yields.
 - The high field efficiency (93.91%) highlights the tool's effectiveness in real-world conditions, reducing operational time and labor costs.

4. Conclusion

The single wheel-driven boom sprayer and sowing attachment demonstrated significant improvements in efficiency and precision over traditional equipment. The boom sprayer achieved a high discharge rate of 1263.25 ml/min, covering four rows simultaneously with minimal spray drift, ensuring uniform pesticide application. Its field efficiency of 80.98% outperformed the knapsack sprayer, reducing operational time and chemical wastage. The sowing attachment exhibited excellent seed uniformity (98.86% for the 4 mm metering device) and low mechanical damage (3%), ensuring precise seed placement and minimal seed loss. With a field efficiency of 93.91%, the tool proved highly effective in real-world conditions, reducing labor and time requirements. This multipurpose tool carrier is a versatile and efficient solution for modern agriculture, particularly for small and marginal farmers. Future work should focus on optimizing the design for diverse crops and field conditions, making it more accessible and sustainable for widespread adoption.

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