



## Performance evaluation of manually operated wheel sprayer

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### Abstract

Mechanization is essential for improving farming processes, making the most use of resources, lowering costs, and increasing operational efficiency. Novel spraying technologies are critical for lowering costs, decreasing chemical effects, and increasing operator safety. This improves crop health management efficiency, lowers pesticide use, reduces environmental contamination, and promotes precision agriculture. Spraying is generally done with a labor-carrying backpack sprayer, which needs more human effort. So, to address the aforementioned issues, a manually operated wheel sprayer is developed, which will benefit farmers in spraying and weeding operations. Nozzle discharge rate increased sharply with operator speed above 2.5 km h<sup>-1</sup>, peaking at 560 ml min<sup>-1</sup>, but is unaffected by travelling distance of the operator. Application rate inversely relates to both speed of the operator and distance travel by the operator, reaching 74-76 l ha<sup>-1</sup> at minimum speed and maximum distance, and falling to 62 l ha<sup>-1</sup> at high speeds over short distances. The mean values of theoretical field capacity, actual field capacity, field efficiency were estimated as machine performance data 0.44 ha h<sup>-1</sup>, 0.32 ha h<sup>-1</sup> and 73 %.

**Keywords:** Chilli, wheel sprayer, nozzle discharge rate, application rate and field efficiency

### Introduction

Chilli (*Capsicum spp.*) is a high-value, warm-season crop cultivated for its pungent fruits, rich in capsaicin, vitamins, and antioxidants. It thrives in well-drained, fertile loamy soils with a pH of 6.0-7.0 (Bosland and Votava, 2012) [1] and requires a warm, frost-free climate (20-30°C) with moderate rainfall, often necessitating irrigation in drier regions. The crop is typically established through nursery-raised seedlings transplanted at 45-60 days old, with spacing varying by variety (30-60 cm between rows, 30-45 cm between plants) (Sahoo *et al.*, 2015) [6]. Harvesting begins 60-90 days after transplanting, with multiple pickings as fruits mature from green to red. Post-harvest, fruits are often sun-dried (Prabhu *et al.*, 2021) [5] or processed into powders, sauces, and oleoresins. Successful chilli production hinges on careful variety selection, precise nutrient and water management, and proactive disease control to ensure high yield and quality.

Traditional agricultural spraying methods face significant challenges, including the uneven application of pesticides, insecticide and herbicide, which can harm crops, human health, and ecosystems. Conversely, integrating modern technologies can optimize chemicals usage (Wu *et al.* 2025 and Gong *et al.* 2024) [2]. Implementing best practices can boost productivity and efficiency in agricultural production systems (Yang *et al.* 2011) [10].

Plant protection is crucial for maximizing crop yields, as agricultural pests cause substantial damage and pose major constraints to production. Effective measures to protect plants are therefore necessary to reduce these losses and to fully realize the benefits of other agricultural inputs.

Crop yields are primarily diminished by pests, diseases, and

weeds. Among control methods, chemical intervention is the most widely used to manage these threats. These chemicals are typically administered either through spraying or dusting. Of these two techniques, spraying is particularly effective and efficient for applying concentrated volumes of protective liquid to crops (Karale *et al.* 2014) [3]. The application of pesticides and liquid fertilizers in agriculture employs various spraying technologies, broadly categorized into hand-operated, engine-operated, and tractor-operated sprayers and dusters. Conventional manual knapsack sprayers, while portable, impose significant ergonomic strain on the operator. This is due to the repetitive motion required for pumping and the weight of the liquid load carried on the back, leading to musculoskeletal fatigue in the back, shoulders, and arms (Matthews, 2018 and Singh *et al.*, 2020) [4, 8]. To mitigate these operational difficulties and improve ergonomics, manually operated wheel-mounted sprayers have been developed.

### Materials and Methods

The existing knapsack sprayer was modified to wheel sprayer with six nozzle and extended boom and second pressure unit attachment as a functional and experimental unit. The design of machine components were based on the principles of operations, tested and compared with the conventional method, to give a correct shape in form of prototype. The mechanical design details were also given with due attention so, as to give adequate functional rigidity for the design of machine. The developed manually operated wheel sprayer consisting of frame, tank, boom, nozzle, pressure unit, nuts and bolts, ground wheel and chain drive.



Fig 1: Cutting of iron bare



Fig 2: Welding to extended portion



Fig 3: Front view of wheel sprayer



Fig 4: Side view of wheel sprayer

### Experimental layout design

The following experimental design was used to achieve the desired objective of optimizing the operating parameters and experimental design. The details of independent and dependent variables considered in this study are given in Table 1.

Table 1: Experimental design for spraying parameters

S. No	Independent variables	Levels	Details	Dependent variables
1	Speed of the operator (Km h <sup>-1</sup> )	3	2.16, 2.64, 2.71	a). Nozzle discharge rate (ml min <sup>-1</sup> )
2	Travelling distance of the operator (m)	3	36, 44, 51	b). Application rate (l ha <sup>-1</sup> )

The ANOVA was used to determine the individual interaction of all independent parameters at 5% significance level and a 95% confidence level. The optimization of the machine parameters was done using RSM of the *Design Expert* software. The optimum values were determined by using the desirability functions and the solution with the highest desirability value was taken as optimum.

### Performance evaluation of manually operated wheel sprayer

The following data were obtained during the field test.

#### 1. Nozzle discharge rate

The nozzle discharge test was performed to measure the volume of liquid discharged from each nozzle and to assess the variation in discharge rates between nozzles. Over one-

minute intervals, the time and discharge data were collected by attaching a plastic bag to each nozzle for measurement.

#### 2. Application rate

The volume application rate is calculated by the using equation 1 (Sharma and Mukesh, 2010) [7].

$$A = \frac{60000 \times D}{S \times W} \quad (1)$$

Where,

A = Application rate, l ha<sup>-1</sup>,  
 D = Nozzle discharge rate, l min<sup>-1</sup>,  
 S = Speed of the operator, km h<sup>-1</sup>,  
 W = Spray swath width, cm.

#### 3. Theoretical field capacity

Theoretical field capacity was calculated using equation 2 (Sharma and Mukesh, 2010) [7].

$$TFC = \frac{S \times W}{10} \quad (2)$$

Where,

TFC = Theoretical field capacity (ha h<sup>-1</sup>),  
 S = Speed of planter (km h<sup>-1</sup>), and  
 W = Width of coverage of sprayer (m).

#### 4. Actual field capacity

Actual field capacity was calculated using equation 3 (Sharma and Mukesh, 2010) [7].

$$AFC = \frac{A}{T} \quad (3)$$

Where,

AFC= Effective field capacity in (ha h<sup>-1</sup>),

A = Actual area covered by planter (ha)

T = Actual time of operation in the field, (h).

### 5. Field efficiency

Field efficiency is the ratio of actual field capacity to theoretical field capacity and expressed as (Sharma and Mukesh, 2010) [7].

$$FE = \frac{AFC}{TFC} \times 100 \quad (4)$$

### 6. Power developed by the operator

According to Sharma and Mukesh (2010) [7] the power of useful work done by human being is given by

$$HP = 0.35 - 0.092 \log t \quad (5)$$

Where,

t = time in minutes

### Results and Discussion

To design the experiment and analysis of data, the ANOVA and Design Expert experimental design analysis were applied to evaluate the effect of treatments (also called control factors or fixed factors) [speed of the operator (A) and travelling distance of the operator (B)] on responses namely nozzle discharge rate and application rate.

Table 2: Optimization parameters for spraying

S. No.	Factors		Mean Response	
	A (Km h <sup>-1</sup> )	B (m)	a) Nozzle discharge rate (ml min <sup>-1</sup> )	Application rate (l ha <sup>-1</sup> )
1	2.71	51	540	66
2	2.64	44	520	65
3	2.64	44	520	65
4	2.16	36	490	75
5	2.64	51	515	64
6	2.71	44	550	67
7	2.71	36	550	67
8	2.64	44	520	65
9	2.64	44	520	65
10	2.16	51	480	74
11	2.64	36	520	65
12	2.16	44	502	76
13	2.64	44	520	65

### Analysis of Variance

Analysis of variance (ANOVA) was used to determine the individual interaction of all of the control factor in the test. In this study, ANOVA was used to analyze the effect of independent variables on dependent variables 5% significant level and a 95% confidence level and the results are summarized in Table 3 and 4.

According to Table 3, the effects of speed of the operator and travelling distance of the operator on nozzle discharge

Rate were significant at 5% significant level. Thus, the most important factor affecting the nozzle discharge rate was speed of the operator.

According to Table 4, the effects of speed of the operator and travelling distance of the operator on application rate were significant at 5% significant level. Thus, the most important factor affecting the application rate was speed of the operator.

Table 3: ANOVA for nozzle discharge rate

Sources	Sum of squares	df	Mean square	F-value	P-value
Speed of the operator, km h <sup>-1</sup> (A)	4698	1	4698	311.51	<0.0001
Travelling distance of the operator, m (B)	100.70	1	100.70	6.68	0.0363
Residual error	105.58	7	15.08		

Significant at 5% level of significance

P<0.05 Determine significance of factor at 95% of confidence level.

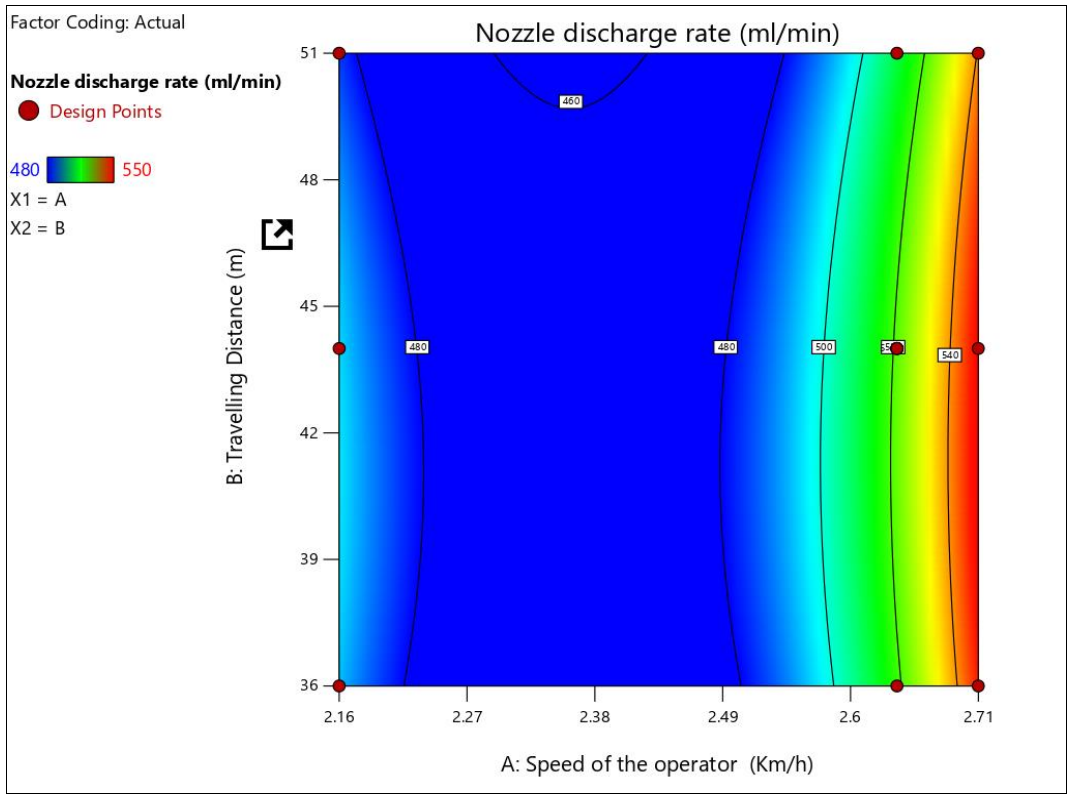
Table 4: ANOVA for application rate

Sources	Sum of squares	df	Mean square	F-value	P-value
Speed of the operator, km h <sup>-1</sup> (A)	4698	1	4698	311.51	<0.0001
Travelling distance of the operator, m (B)	100.70	1	100.70	6.68	0.0363
Residual error	105.58	7	15.08		

### Analysis of the operating parameters for nozzle discharge rate

The relationship between the Speed of the operator (A) and the travelling distance (B) on the nozzle discharge rate (ml min<sup>-1</sup>), contour plot 5(a). The graph indicates that as the

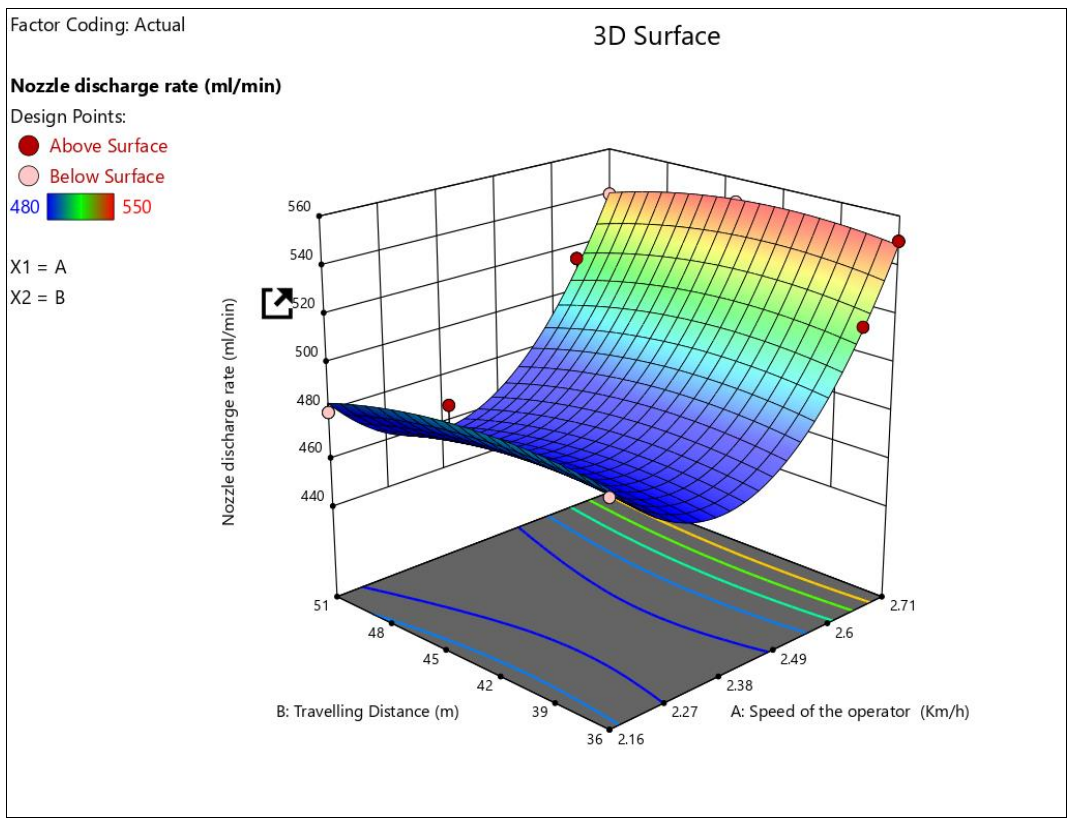
operator's speed increases beyond approximately 2.5 Km h<sup>-1</sup>, there is a significant rise in the discharge rate. In contrast, the travelling distance appears to have a minimal impact on the discharge rate.



5(a). Contour plots for A and B

The effects of two factors on the nozzle discharge rate ( $\text{ml min}^{-1}$ ) are shown in 3D surface plot 5(b). The operator's speed (A) and the distance traveled (B). As the operator's speed increases, the surface exhibits a distinct upward trend, especially after  $2.5 \text{ km h}^{-1}$ , when the discharge rate increases toward its maximum of  $560 \text{ ml min}^{-1}$ . Interestingly, the

comparatively consistent curvature along that axis indicates that the influence of the travelling distance is significantly less pronounced. The color gradient, which goes from blue (lower rates) to red (higher rates), highlights the fact that the operator's movement speed is the main determinant of the nozzle's discharge rate.



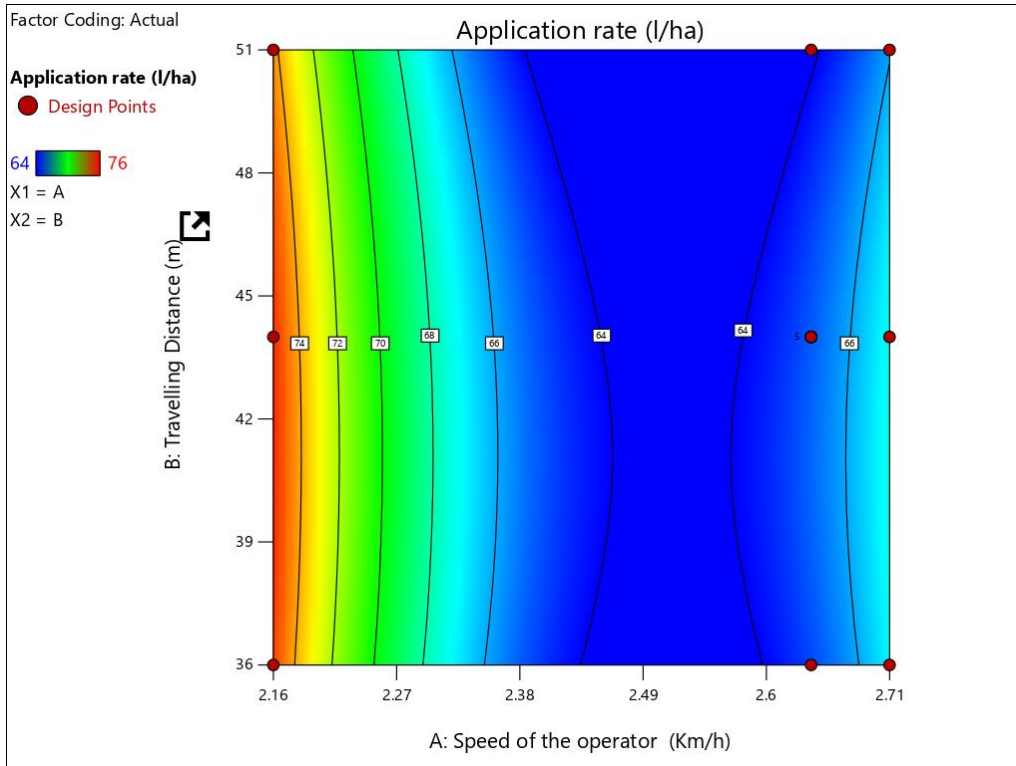
5(b). Response surface for A and B

Fig 5: Effect of different factors on nozzle discharge rate

**Analysis of the operating parameters for application rate**

The application rate ( $l\ ha^{-1}$ ) is influenced by the interaction between operator speed and travelling distance, as illustrated in contour plot 6(a). The near-vertical contour lines on the graph show that speed is the main factor influencing the application rate, when speed rises from 2.16

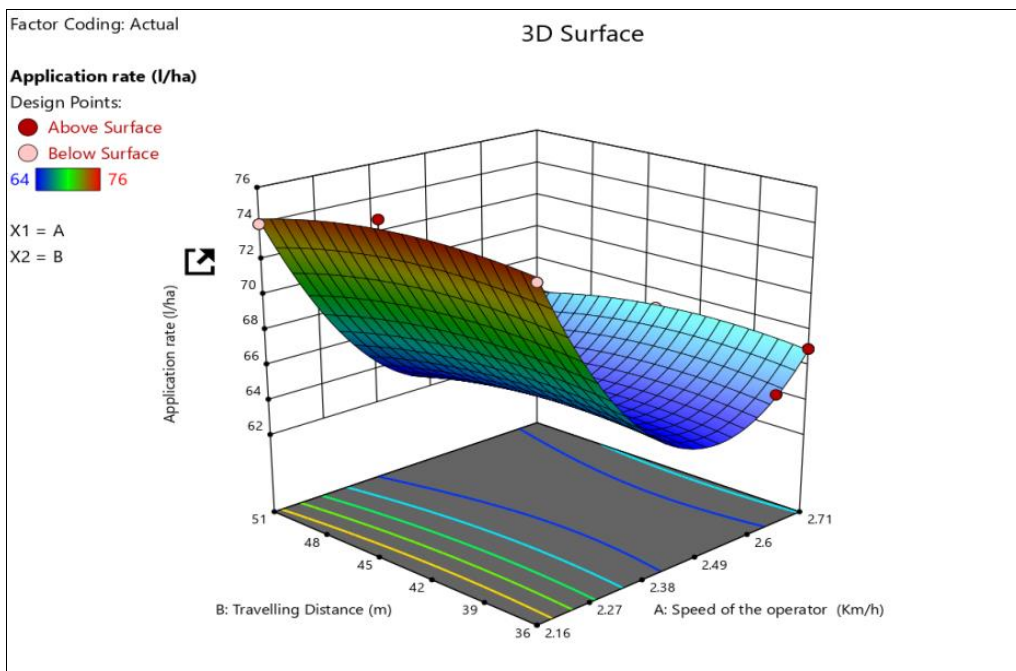
to  $2.71\ km\ h^{-1}$ , the application rate dramatically drops from about  $76\ l\ ha^{-1}$  to  $64\ l\ ha^{-1}$ . The most stable application zone is at higher speeds (between  $2.49$  and  $2.6\ km\ h^{-1}$ ), where the rate is constantly low regardless of the distance traveled, but traveling distance has a slight impact.



**6(a).** Contour plots for A and B

The effect of operator speed (A) and travel distance (B) on the final application rate in liters per hectare is shown in 3D surface graph 6(b). According to the graph, when the speed is at its lowest ( $2.16\ km\ h^{-1}$ ) and the traveling distance is at its maximum (51 m), the application rate is at its highest,

reaching roughly  $74-76\ l\ ha^{-1}$ . On the other hand, as the operator's speed rises near  $2.71\ km\ h^{-1}$ , particularly at shorter travel lengths, the application rate falls to its lowest values, approximately  $62\ l\ ha^{-1}$ .



**6(b).** Response surface for A and B

**Fig 6:** Effect of different factors on application rate

It is evident from Table 5 those average values of theoretical field capacity, actual field capacity and field efficiency were

estimated as Machine performance data 0.44 ha h<sup>-1</sup>, 0.32 ha h<sup>-1</sup> and 73 % respectively.

**Table 5:** Field capacity of manually operated wheel sprayer

S. No.	Width of the sprayer (m)	Speed of the operator(km h <sup>-1</sup> )	Theoretical field capacity (ha h <sup>-1</sup> )	Actual field capacity (ha h <sup>-1</sup> )	Field efficiency (%)
1	1.8	2.16	0.38	0.28	73
2	1.8	2.64	0.47	0.34	72
3	1.8	2.71	0.48	0.36	75
Average	1.8	2.50	0.44	0.32	73

### Conclusion

Based on the study undertaken, following conclusions can be drawn.

- The nozzle discharge rate increases as both the speed of the operator and the travelling distance increase. The highest discharge rates are achieved when both variables are at their maximum values.
- The application rate is increased when both operator speed and travelling distance are at their minimum values. As both independent variables increase, the application rate undergoes a significant.
- The average values of theoretical field capacity, actual field capacity and field efficiency were observed, 0.44 ha h<sup>-1</sup>, 0.32 ha h<sup>-1</sup> and 73 % respectively.
- The results of ANOVA showed that speed of the operator and travelling distance are the significant parameters.
- The power developed by the operator for operating the machine was observed to be average 0.12 hp.

### Acknowledgement

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