# Optimization of operational parameters for tractor operated swinging lance sprayer using Taguchi design

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**Abstract:** Application of pesticide in recommended dose not only reduces the input cost of chemical but also reduces the ill effects due to excess application of pesticide on crop and environment. A tractor operated swinging lance sprayer was developed for the effective application of chemicals. To standardize optimum operational parameters, the effect of various operational parameters was investigated by using Taguchi design. The operational parameters, such as spacing between spray guns($s$), spray gun height ($h$), swing angle($a$) and operating pressure ($p$) were selected as independent parameters, whereas swath width ($S_w$), and overlap ($O_p$) were considered as performance evaluation characteristics. For conducting experiments and analysis of experimental data, Taguchi design was considered using Minitab.17 software tool. The optimum combination obtained from the Taguchi design significantly improved the swath width by 38% with the targeted overlap of 40%. After analyzing ANOVA results, it was seen that the sprayer performance in terms of $S_w$ was greatly influenced by swing angle, in case of $O_p$ was greatly influenced by spacing between spray guns. Furthermore, predictive model equations were developed by using regression models for predicting the $S_w$ as well as $O_p$.

**Keywords:** swinging lance sprayer, Taguchi design, optimization, Modeling, Minitab

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## 1 Introduction

The critical role played by plant protection practices is well recognized. Direct yield losses range between 20% and 40% of global agricultural productivity due to pathogens, animals, and weeds (Oerke, 2006). The production loss due to pests estimated in India is US$ 42.66 million annually (Devi et al., 2017). The increased damage to crops due to pests and subsequent losses results in serious threat to food security. While relatively lower effective, the world’s crop production cost included the cost of pesticides, worth over $25 billion per year along with more than 2.25 billion kilograms of active ingredient dispensed into the ecosystem annually. Much inefficiency exists in depositing pesticides onto target-plant surfaces, often resulting in 60% to 70% off-target losses (Bikram, 2017).

Application of pesticide in recommended dose not

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only reduces the input cost of chemical but also reduces the ill effects due to excess application of pesticide on crop and environment. A 40%-50% reduction in pesticide consumption reduces the protection cost from USD50/ha to lower than USD30/ha (Kumar et al., 2020). Application methods should be designed to increase application efficiency so that food production target of 333 million MT by 2050 can be achieved without vitiating environment and jeopardizing human health. Therefore, one of the viable options to protect environment and ensure food security increasing the application efficiency of chemicals. The adjustment of operational parameters of any sprayer based on crop was critical to achieve best performance of sprayer.

Tractor mounted gun type sprayer with hose pipe length 60 – 300 m, was popular in many parts of India due to its high field capacity, low application cost and versatility for multi crop usage (Kumar et al., 2020). However, a tractor mounted gun-type sprayer required four persons, out of which two are for operating spray guns, one for handling hose pipes and one for operating tractor (Narang et al., 2015). Though this method gives satisfactory pest control, it consumes a large volume of liquid per hectare. The application rate of gun sprayer was 900 L ha$^{-1}$, which is very high compared to recommend application rate. The spray swath depends on the movement of the spray gun by the operator. Uneven distribution was a significant drawback from conventional spraying due to varying swing speed and distance by the operator (Hermosilla et al., 2011). On the other hand, the operators were exposed to the chemical spraying in front of his way. The dermal exposure with a manually operated gun sprayer is very high; a human-driven vehicle with fixed boom and constant spray volume can reduce dermal exposure by 60-fold compared with manual gun spraying (Nuyttens et al., 2007). Despite the popularity of tractor operated gun-type sprayer among the farming community, eliminating bottlenecks in the technology could improve the spraying activity in terms of efficiency and cost. Automation of swinging of spray guns could improve spraying efficiency in terms of uniform application, and reduction in chemical losses. Hence, a tractor operated swinging lance sprayer was developed with automation of spray gun operation by eliminating manual operation of spray guns. The effect of operational parameters on sprayer performance was investigated, and optimum operational parameters were identified for better performance of the sprayer.

To the author’s knowledge, no significant work carried out on swinging lance spraying technique and no significant research findings reported. In the present study, the Taguchi design used to study the influence of various operational parameters on performance of sprayer, and optimum combination of operational parameters was identified. Further, mathematical models were developed for prediction of swath width as well as overlap by using regression analysis.

## 2 Material and methods

### 2.1 Development of tractor operated swinging lance sprayer

The developed swinging lance sprayer consists of MS rectangular frame of size 3200 × 920 × 1550 mm (L × W ×H) for mounting of various components such as chemical tank, pump, power transmission system, swinging mechanism, hose pipes, spray guns and three-point hitch system. The power transmission system consists of a universal coupling fitted to tractor PTO, one shaft of diameter 32 mm, two bearings (P-206), followed by 178 mm diameter pulley attached with shaft. The PTO rotated the shaft pulley, the shaft pulley connected to pump pulley of size 101mm through V-belt (A-81). Power transmission system operated the piston type pump for spraying of chemical. The crank – rocker type four bar mechanism converts the rotary motion of DC motor (12 V, 50 W, 30 N-m torque) with worm gear arrangement into swinging operation of spray gun. a horizontal cylindrical shape PVC chemical tank of size 1700mm length with diameter of 550 mm, and capacity of 400 liters was placed on the frame. The minimum spacing between spray guns was 2 m, there was provision to extend the boom length either side by 0.3 m, 0.6 m. Hence, there was three provision to adjust spacing between spray guns based on requirement, i.e 2 m, 2.6 m, and 3.2 m. The minimum spray gun height from ground level was 0.9 m. There was three provision to adjust spray gun height based on crop height, i.e 0.9 m, 1.2m, and 1.4m.The maximum swing angle was 120° with the developed crank-rocker mechanism. There was provision to adjust the swing angle by reducing or increasing the length of coupler link. Three swinging angle adjustment provision provided with developed sprayer, i.e 100°, 110°, and 120°. The isometric view of developed swinging lance sprayer was shown in Figure 1.

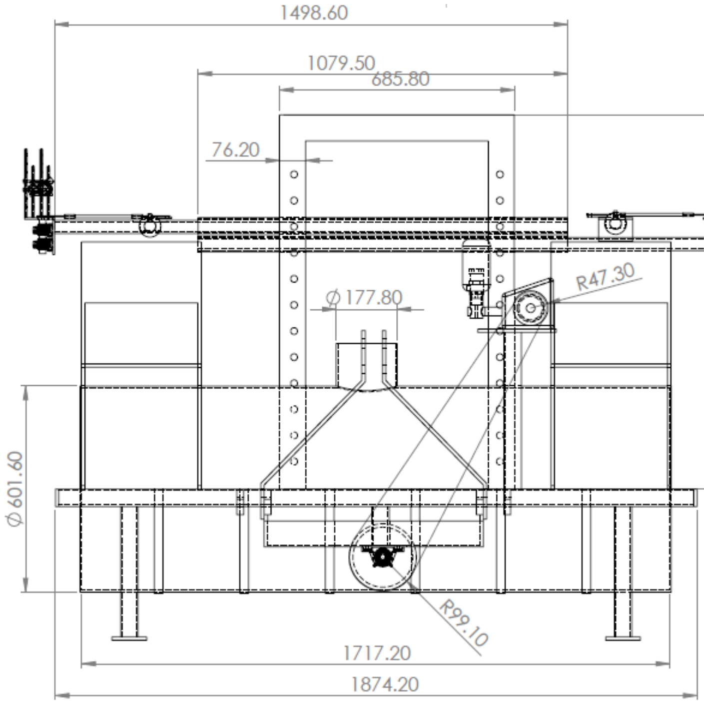


Figure 1 Isometric view of tractor operated swinging lance sprayer

## 2.2 Taguchi design

To conduct experiment with full factorial design, in total 243 experimental runs ($3^4 \times 3$) need to conduct, which was laborious, time consuming and loss of inputs such as fuel, water, time and manpower. Hence, Taguchi design considered for optimization of operational parameters to reduce number of experimental runs. Taguchi design is one of the robust designs to optimize quality parameters in engineering production (Taguchi, 1987). Taguchi design determines the best settings of process parameters that influence product performance variation and fine-tuning those process parameters that influence the average performance (Sivaiah and Chakradhar, 2018). The Taguchi design steps consist: (i) to select factors to be optimized (output); (ii) to select factors affecting output(input); (iii)to fix orthogonal array; (iv) to arrange factors in orthogonal array; (v) to perform experiment; (vi) analyze the data using ANOVA and S/N ratio; (vii) to finalize optimum combination; (viii) to confirm results (De Souza et al., 2013).

Taguchi used the term signal and noise which represents wanted value (mean) for the response and unwanted value (standard deviation) for the response. Taguchi has divided the S/N ratio into to three categories based on the requirements of response namely larger is better, smaller is better and nominal is best. In the present study, for swath width larger is better and for overlap smaller is better considered for effective spraying operation. Hence, Equations 1 and 2 have been used to calculate the S/N ratios for $S_w$ and $O_p$ respectively.

S/N ratio for the larger is better = $-10\log\frac{1}{n}\sum\frac{1}{(R)^2}$ (1)

S/N ratio for the smaller is better =$-10\log\frac{1}{n}\sum(R)^2$ (2)

Where, $n$ is the number of observations, and $R$ is the observed data for each response.

The operational parameters considered for the study and their levels were shown in Table 1. In the Taguchi design, number of experiments, and experimental combination obtained from Taguchi orthogonal array only need to conduct. Taguchi orthogonal array was generated using minitab.17 software tool, Table 2. In total nine experimental combinations, each at three replications was sufficient to study the influence of various operational parameters on sprayer performance without compromising on any data.

**Table 1 Operational parameters and their levels**

| S.No | Factor | Symbol | Unit | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|---|
| 1 | Spacing between spray guns | s | m | 2.0 | 2.6 | 3.2 |
| 2 | Spray gun height | h | m | 0.9 | 1.2 | 1.4 |
| 3 | Swing angle | a | ° | 100 | 110 | 120 |
| 4 | Pressure | p | Kg cm$^{-2}$ | 18 | 21 | 25 |

**Table 2 Orthogonal array ($L_9$) of Taguchi design**

| Exp. runs | Parameters: Spacing between spray guns ($s$), m | Spray gun height ($h$), m | Swing angle ($a$),° | Operating Pressure ($p$), kg cm$^{-2}$ |
|---|---|---|---|---|
| 1 | $s_1$ | $h_1$ | $a_1$ | $p_1$ |
| 2 | $s_1$ | $h_2$ | $a_2$ | $p_2$ |
| 3 | $s_1$ | $h_3$ | $a_3$ | $p_3$ |
| 4 | $s_2$ | $h_1$ | $a_2$ | $p_3$ |
| 5 | $s_2$ | $h_2$ | $a_3$ | $p_1$ |
| 6 | $s_2$ | $h_3$ | $a_1$ | $p_2$ |
| 7 | $s_3$ | $h_1$ | $a_3$ | $p_2$ |
| 8 | $s_3$ | $h_2$ | $a_1$ | $p_3$ |
| 9 | $s_3$ | $h_3$ | $a_2$ | $p_1$ |

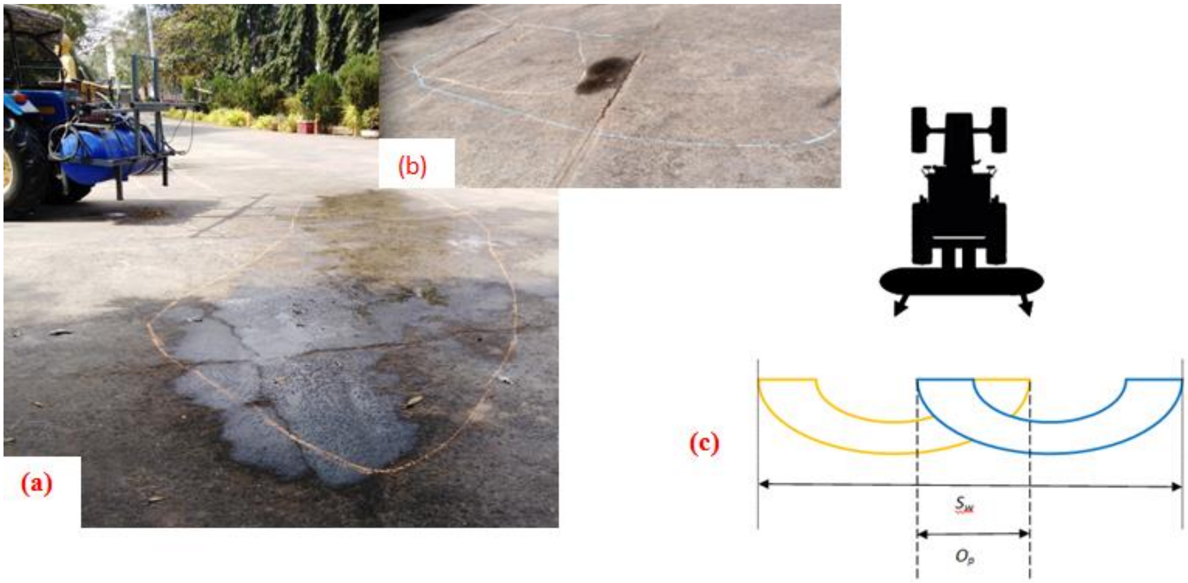
Note: ($s$=2, 2.6, 3.2m ; $h$=0.9, 1.2, 1.4m; $a$= 100°; 110°; 120°: $p$=18 kg cm$^{-2}$, 21 kg cm$^{-2}$, 25 kg cm$^{-2}$)

### 2.3 Experimental procedure to optimize operational parameters

A laboratory study was conducted to study the influence of various operational parameters on sprayer swath width, and overlap to identify the optimum combination of operational parameters for the developed sprayer. The experiment was conducted on the concrete floor, tap water used as a spray solution. Swinging lance spray attached to the tractor; the tractor was at a neutral position. Initially, the left spray gun was operated for 2 minutes, whereas the right spray gun was in off condition, the wetted perimeter on a concrete floor for the left spray gun marked with orange colour, Figure 2(a). Later, the right spray gun was operated for 2 minutes, whereas the left spray gun was in off condition, the wetted perimeter on a concrete floor for the right spray gun marked with blue colour, Figure 2(b). For each run, swath width, and overlap were measured, Figure 2(c).

## 3 Results and discussion

The swath width and overlap of sprayer were measured at each experimental run. The Signal – to – Noise (S/N) ratios were calculated for each experimental run with Minitab tool. The experimental results and S/N ratios were given in Table 3.



(a) Marking of wetted perimeter for left spray gun (b) Marked wetted perimeters for both the spray guns (c) A typical representation of swath width and overlap

Figure 2 Measurement of swath width and overlap with developed sprayer

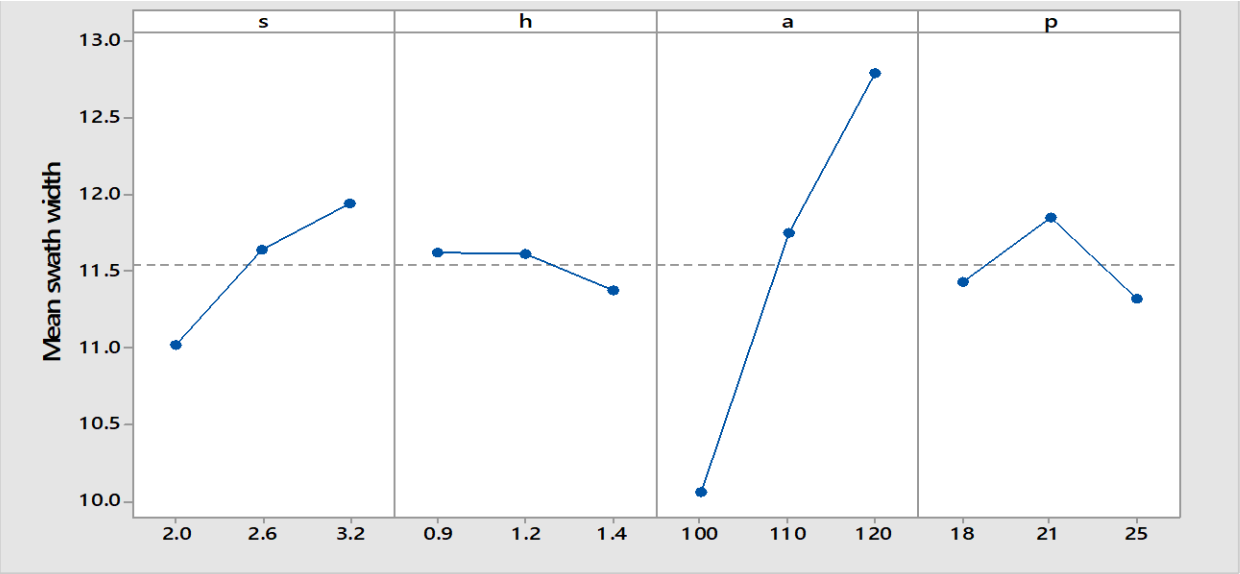


Figure 3 Main effects plot showing influence of factors on swath width

**Table 3 Experimental results and their S/N ratios**

| Exp. runs | Parameters | | | | Experimental results | | S/N ratios of results | |
|---|---|---|---|---|---|---|---|---|
| | $s$ (m) | $h$(m) | $a$(°) | $p$(kg cm$^{-2}$) | $S_w$ (m) | $O_p$ (m) | $S_w$(dB) | $O_p$(dB) |
| 1 | 2 | 0.9 | 100 | 18 | 9.5 | 9.4 | 19.585 | -19.432 |
| 2 | 2 | 1.2 | 110 | 21 | 11.6 | 7.8 | 21.314 | -17.842 |
| 3 | 2 | 1.4 | 120 | 25 | 11.9 | 6.2 | 21.511 | -15.894 |
| 4 | 2.6 | 0.9 | 110 | 25 | 11.7 | 7.7 | 21.388 | -17.767 |
| 5 | 2.6 | 1.2 | 120 | 18 | 12.9 | 6.4 | 22.189 | -16.169 |
| 6 | 2.6 | 1.4 | 100 | 21 | 10.3 | 5.8 | 20.285 | -15.318 |
| 7 | 3.2 | 0.9 | 120 | 21 | 13.6 | 6.1 | 22.671 | -15.707 |
| 8 | 3.2 | 1.2 | 100 | 25 | 10.3 | 5.8 | 20.285 | -15.269 |
| 9 | 3.2 | 1.4 | 110 | 18 | 11.9 | 6.5 | 21.511 | -16.258 |

**Table 4 Mean S/N ratio response table for swath width**

| Symbol | Operating Parameters | Mean S/N ratio<br>Level 1 | Level 2 | Level 3 | Delta | Rank |
|---|---|---|---|---|---|---|
| s | Spacing between spray guns | 20.8 | 21.29 | 21.49 | 0.69 | 2 |
| h | Spray gun height | 21.21 | 21.26 | 21.1 | 0.16 | 4 |
| a | Swing angle | 20.05 | 21.4 | 22.12 | 2.07 | 1 |
| p | Pressure | 21.1 | 21.42 | 21.06 | 0.36 | 3 |

### 3.1 Effect of operational parameters on swath width ($S_w$)

The effect of operational parameters on swath width was shown in Figure 3. It was observed that swath width ($S_w$) increased with increase in spacing between spray guns, and swing angle. Similar agreement between spacing between spray guns, and swath width reported (Udaybhaskar et al., 2018). It was also observed that swath width ($S_w$) decreases with increase in spray gun height. As the pressure increases swath width ($S_w$) also increased up to certain level, a further increase in pressure reduces swath width ($S_w$). This was in conformity with the reports given by (Nagesh, 2017). The mean S/N ratio response table obtained through Taguchi design indicates that the swath width was significantly influencing by swing angle followed by spacing between spray guns with delta values 2.07, 0.69, Table 4.

### 3.2 Effect of operational parameters on overlap ($O_p$)

The effect of operational parameters on overlap was shown in Figure 4. It was observed that as increases in spacing between spray guns, height of spray gun and swing angle the overlap ($O_p$) decreased. It was also observed that with increase of pressure overlap ($O_p$) decreased up to certain level, a further increase in pressure increases overlap ($O_p$). The mean S/N ratio response table obtained from Taguchi design indicates that the overlap was significantly influencing by spacing between spray guns, and spray gun height with delta values 1.98, 1.81, Table 5.

**Table 5 Mean S/N ratio response table for overlap**

| Symbol | Operating Parameters | Mean S/N ratio<br>Level 1 | Level 2 | Level 3 | Delta | Rank |
|---|---|---|---|---|---|---|
| s | Spacing between spray guns | -17.72 | -16.42 | **-15.74** | 1.98 | 1 |
| h | Spray gun height | -17.64 | -16.43 | **-15.82** | 1.81 | 2 |
| a | Swing angle | -16.67 | -17.29 | **-15.92** | 1.37 | 3 |
| p | Pressure | -17.29 | **-16.29** | -16.31 | 1 | 4 |

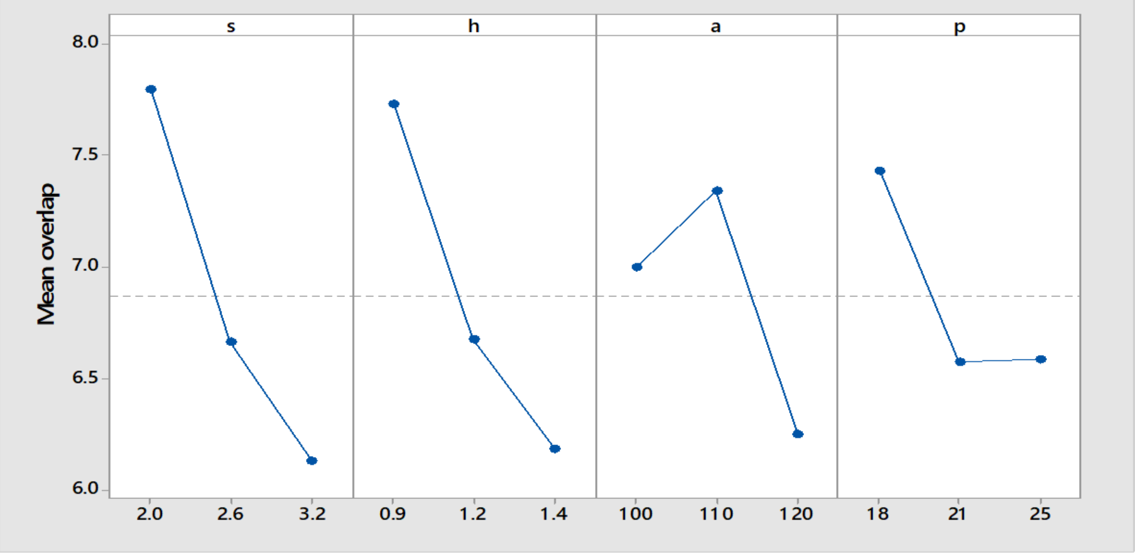


Figure 4 Main effects plot showing influence of factors on overlap

### 3.3 Application of response optimizer to optimize operational parameters

The maximum swath width of 13.60 m was observed. The required overlap was 5.44 m (40% of maximum swath width). Composite optimum combination plot was prepared by considering maximum swath width and targeted overlap of 5.44 m. The observed optimum combination was, spacing between spray guns at 3.19 m, spray gun height at 1.11 m, swing angle at 120°, and pressure at 20.34 kg $cm^{-2}$ with desirability of 1.00, Figure 5. Hence, the optimum combination of operational parameters was $s_3 – h_2 – a_3 – p_2$.

### 3.4 Confirmation test to verify optimum combination

The optimum combination of operational parameters obtained from analysis of data needs to verify. A confirmation experiment was conducted to validate arrived optimum combination. First, the results obtained from the initial combination ($s_3$-$h_2$-$a_1$-$p_3$) was considered. Then, the experiment was conducted to identify swath width and overlap of developed sprayer with optimum combination of operational parameters ($s_3$-$h_2$-$a_3$-$p_2$). The optimum combination of operating parameters increased swath width by 34.0% and reduced overlap by 6.9%. The optimum combination produced maximum swath width with targeted overlap of 40%, Table 6.

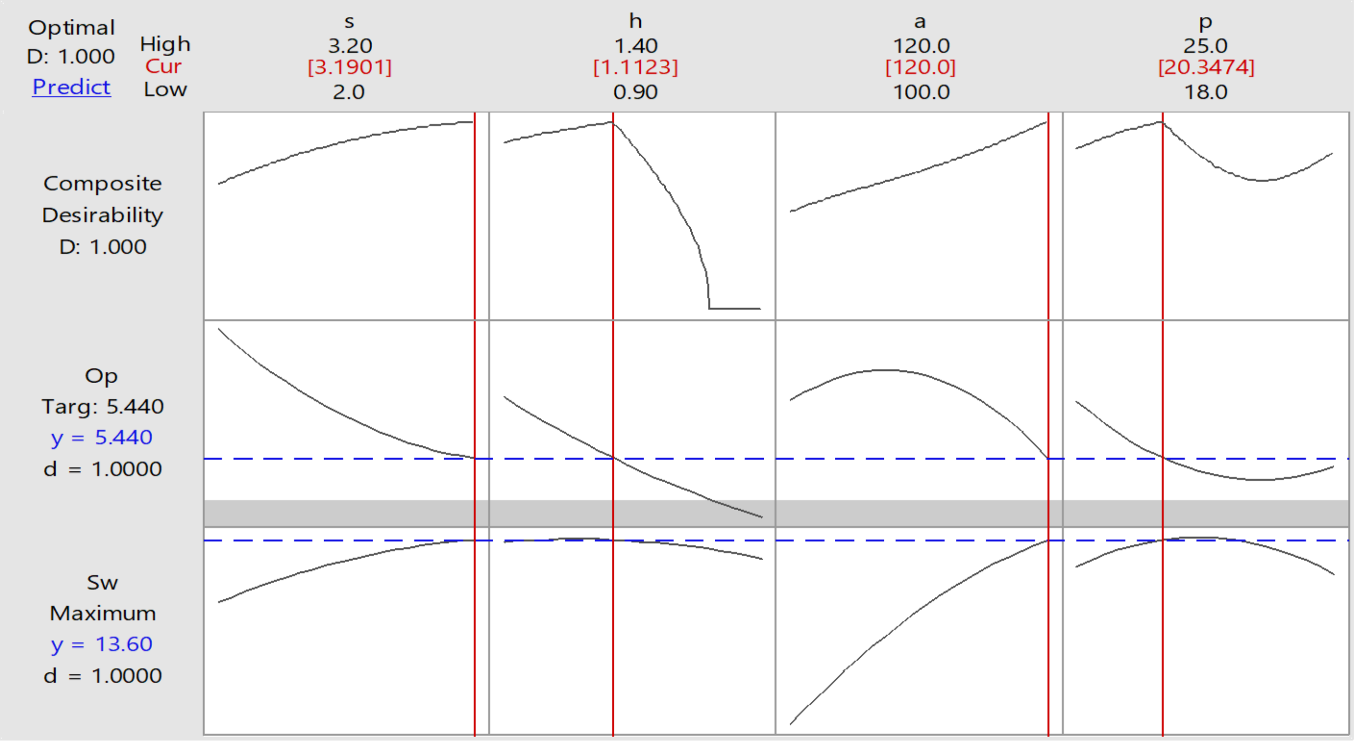


Figure 5 Composite optimization plot

### 3.5 ANOVA for swath width ($S_w$) and overlap ($O_p$)

ANOVA gives the operational parameter that mostly affects the performance characteristics. It was found that $S_w$ was significantly influenced by swing angle followed by spacing between spray guns. The percentage contribution of swing angle, spacing between spray guns, operating pressure and height of spray gun on $S_w$ was 86.63%, 9.72%, 3.13% and 0.53% respectively. The overlap was mostly influenced by spacing between spray guns followed by height of spray gun, swing angle and operating pressure. The respective percentage contribution of spacing between spray guns, height of spray gun, swing angle and operating pressure on $O_p$ was 38.10 %, 32.05 %, 17.62 % and 12.23% respectively, Table 7.

**Table 6 Confirmation test results**

| | Initial combination | | Optimum combination |
|---|---|---|---|
| combination | $s_3$-$h_2$-$a_1$-$p_3$ | | $s_3$-$h_2$-$a_3$-$p_2$ |
| Swath width(m) | 10.3 | | 13.6 |
| %increase of swath width | | **34.0%** | |
| overlap(m) | 5.8 | | 5.4 |
| %reduction in overlap | | **6.9%** | |

**Table 7 Contribution of factors on swath width and overlap of sprayer**

| source | Df | Swath width | | | Overlap | | |
|---|---|---|---|---|---|---|---|
| | | sum of squares | Mean squares | % contribution | sum of squares | Mean squares | % contribution |
| S | 2 | 0.74495 | 0.37248 | 9.72 | 6.0689 | 3.03444 | **38.10** |
| H | 2 | 0.04072 | 0.02036 | 0.53 | 5.1062 | 2.5531 | 32.05 |
| A | 2 | 6.64171 | 3.32085 | **86.63** | 2.8075 | 1.40375 | 17.62 |
| P | 2 | 0.23975 | 0.11988 | 3.13 | 1.9479 | 0.97393 | 12.23 |
| Total | 8 | 7.66713 | | 100 | 15.9304 | | 100.00 |

## 3.6 Modeling

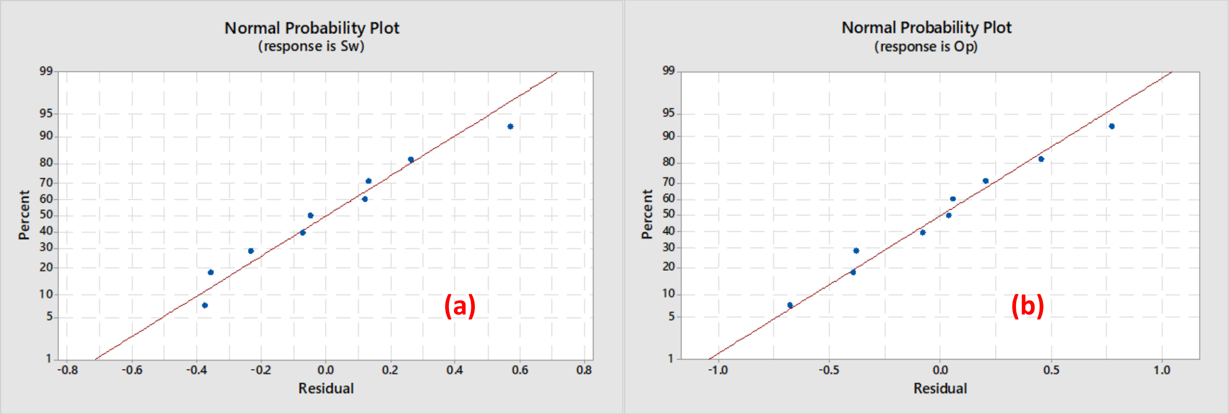
Linear regression analysis performed using Minitab 17.0 software tool to develop predictive models to estimate $S_w$ and $O_p$ as a function of spacing between spray guns, height of spray gun, swing angle and operating pressure. The mathematical equations derived from the regression analysis are shown in the Equations 3 and 4 for $S_w$ and $O_p$ respectively.

$$S_w = -4.57 + 0.769s - 0.456h + 0.1361a - 0.00111p \quad (R^2 = 94.27\%) \qquad (3)$$

$$O_p = 20.75 - 1.389s - 3.12h - 0.0372a - 0.00844p \quad (R^2 = 85.81\%) \qquad (4)$$

The developed regression models for $S_w$ and $O_p$ were having high $R^2$ values as 94.27 % and 85.81 % respectively. It was observed that the residuals fall near the straight line for both $S_w$ and $O_p$, which implies that the developed model coefficient models were significant.

Conformation tests were performed to validate the predicted models and data were presented in Table 8. Experimental results were taken randomly from Table 3 for $S_w$ and $O_p$ and prediction has been done by using developed models for $S_w$ and $O_p$. It was observed that predicted results from the models have good agreement with experimental results. The observed percentage error ranges from 0.35% to 6.58%.



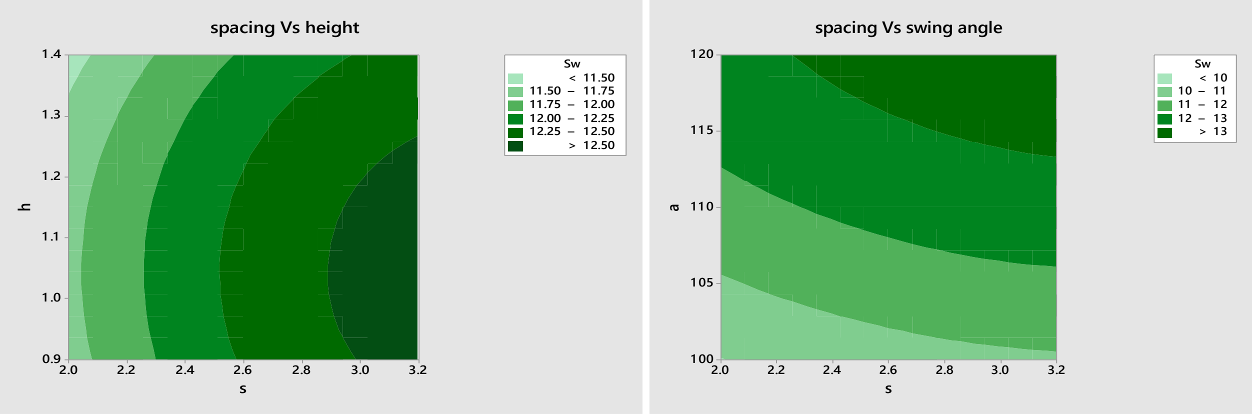
(a)swath width (b) overlap

Figure 6 Normal probability plot of the residuals

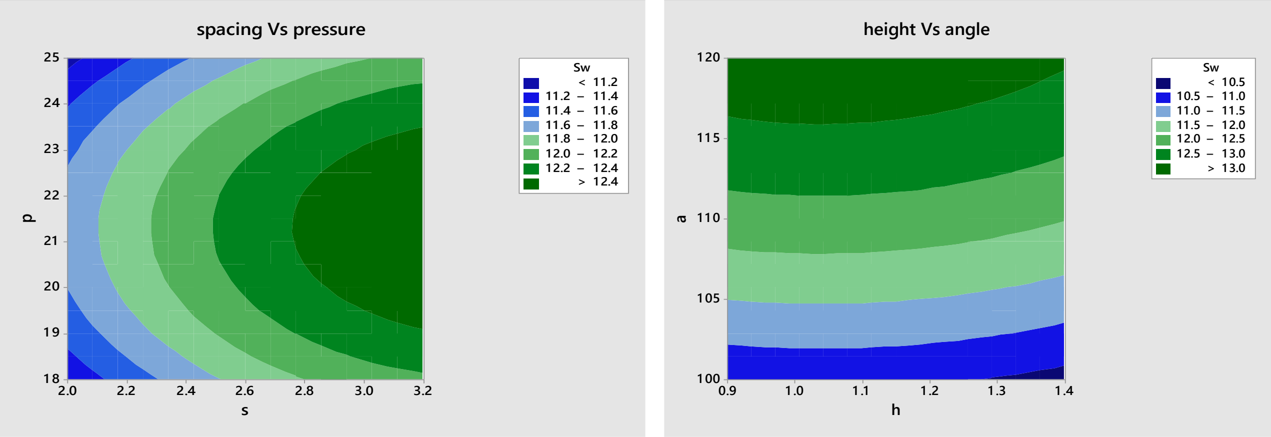
Contour plots examining the relationship between operational parameters and swath width was shown in Figure 7. From Figure 7(a) it was found to be high level of spacing between spray guns and medium level of spray gun height leads to generate more swath width. Figure 7(b) shows that more swath width could be attained at high level of spacing between spray guns and high level of swing angle. It was clear from fig 7(c) that medium level of spray gun height and high level of swing angle could yield more swath width. Fig 7(d) depicts that high level of spacing between spray guns and medium level of pressure leads to generate more swath width. Similarly medium level of pressure, medium level of spray gun height and medium level of pressure, high level of swing angle leads to generate more swath width as shown in Figure 7 (e-f). Fig 8 was contour plots to examine the relationship between operational parameters and overlap. From Figure 8(a-c), it was noticed that low overlap could be obtained at high level of spacing between spray guns, high level of spray gun height and high level of swing angle. Similarly, less overlap could be attained with medium level of pressure as shown in Figure 8(d-f).

**Table 8 Confirmation results for the developed models**

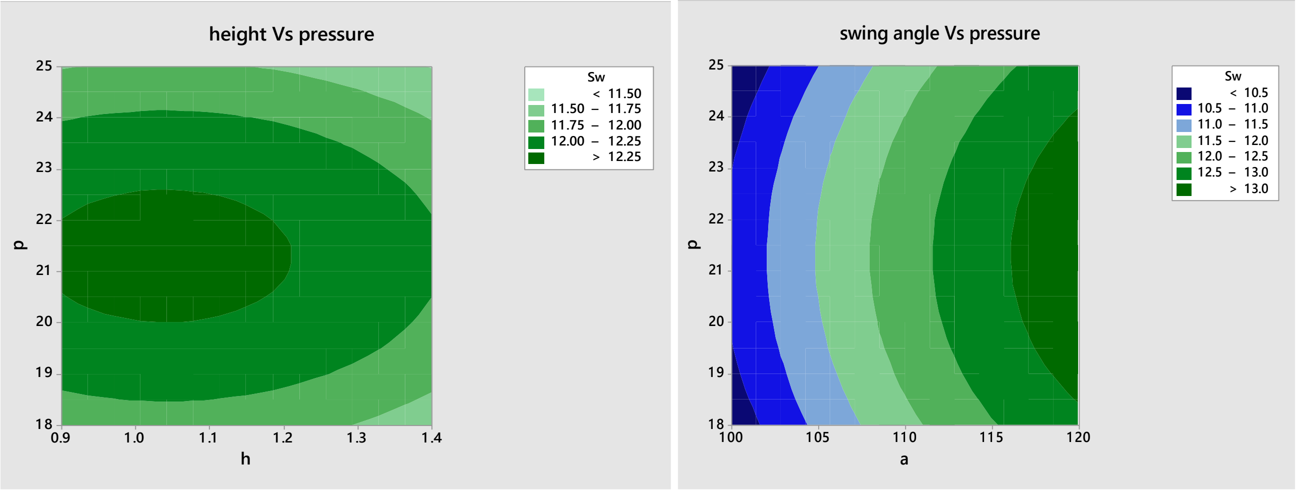
| | Experimental | | Predicted | | Residuals | | Error % | |
|---|---|---|---|---|---|---|---|---|
| Run | $S_w$ | $O_p$ | $S_w$ | $O_p$ | $S_w$ | $O_p$ | $S_w$ | $O_p$ |
| 1 | 9.5 | 9.4 | 9.89 | 9.33 | -0.36 | 0.03 | -3.74 | 0.35 |
| 2 | 11.6 | 7.8 | 11.06 | 7.6 | 0.57 | 0.2 | 4.94 | 2.51 |
| 3 | 11.9 | 6.2 | 12.27 | 6.19 | -0.37 | 0.05 | -3.14 | 0.76 |
| 5 | 12.9 | 6.4 | 12.94 | 6.82 | -0.07 | -0.39 | -0.54 | -6.02 |
| 7 | 13.6 | 6.1 | 13.48 | 6.5 | 0.12 | -0.4 | 0.89 | -6.58 |



(a) spacing between spray guns Vs spray gun height (b)spacing between spray guns Vs swing angle

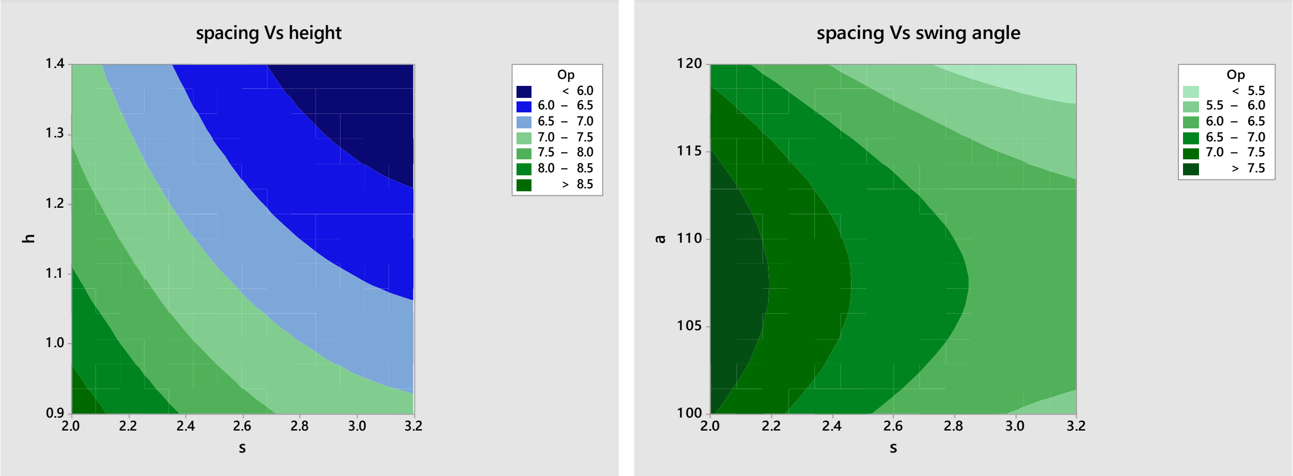


(c) spacing between spray guns Vs pressure (d) spray gun height Vs swing angle

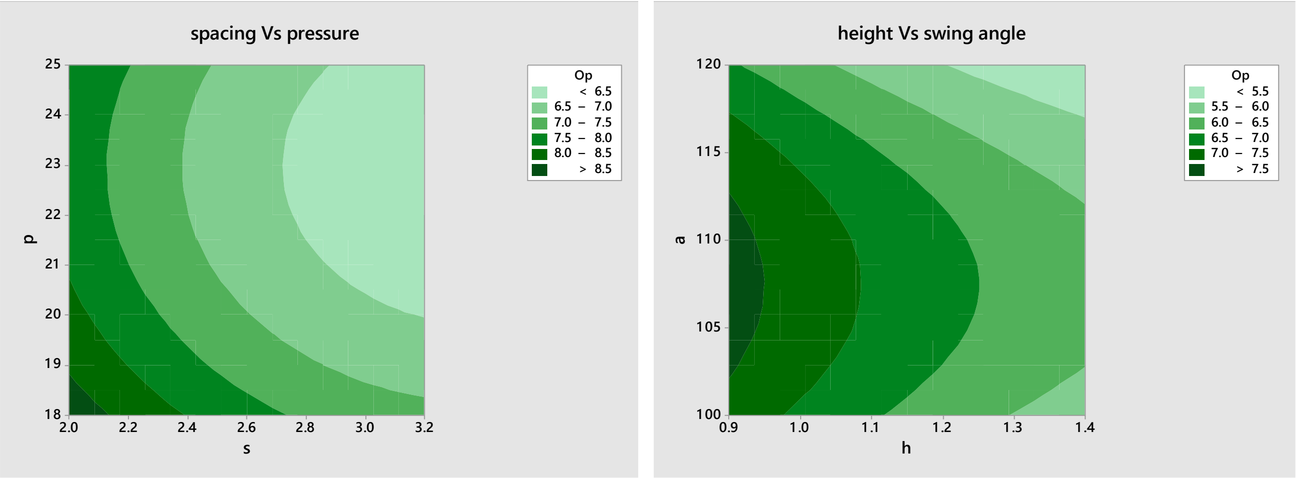


(e) spray gun height Vs pressure (f) swing angle Vs pressure

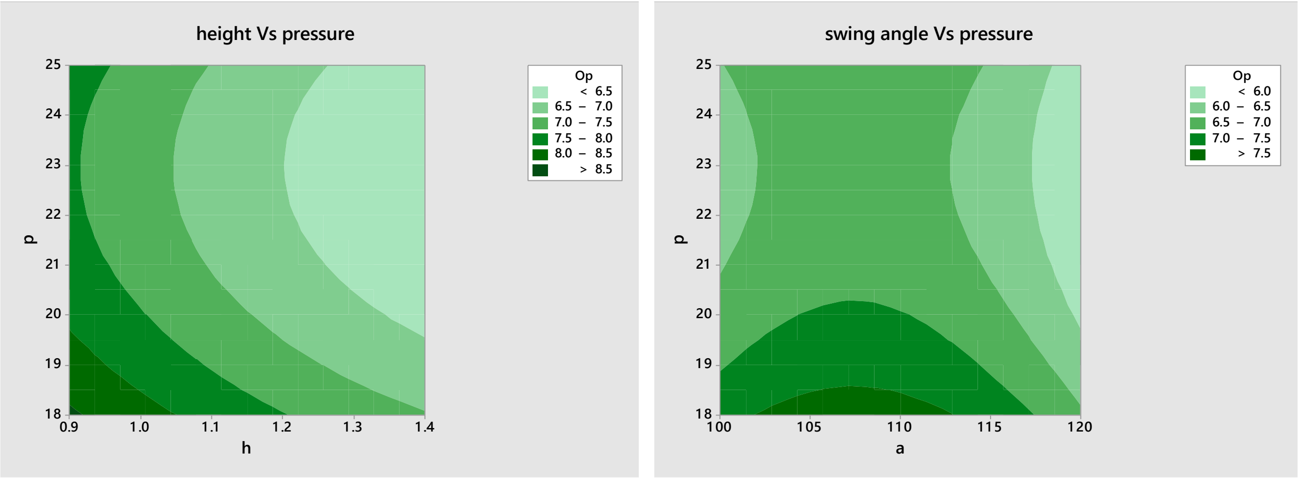
Figure 7 Contour plots showing influence of factors on swath width for high discharge spray gun



(a) spacing between spray guns Vs spray gun height (b) spacing between spray guns Vs swing angle



(c) spacing between spray guns Vs pressure (d) spray gun height Vs swing angle



(e) spray gun height Vs pressure (f) swing angle Vs pressure

Figure 8 Contour plots showing influence of factors on overlap for high discharge spray gun

## 4 Conclusion

Taguchi method significantly reduced number of experiments from 243 to 27 without compromising and neglecting any operational parameter. The optimum combination of operational parameters for effective swath width was $s_3$ - $h_2$ - $a_3$ - $p_2$ and it was observed that 34% of increase in swath width and 6.9% of reduction of overlap. It was observed that swing angle greatly influenced swath width, whereas spacing between spray guns mostly influenced overlap. The obtained optimum operation combination for swath width and overlap significantly improved the performance of spraying activity. A close agreement observed between predicted results and experimental results; hence, the developed models could be used for proper selection of operational parameters without conducting experiments.

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