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Harkal AD
Research Scholar, CAET,
VNMKV, Parbhani, Maharashtra
India

Ramteke RT
Associate Dean and Principal,
CAET, VNMKV, Parbhani,
Maharashtra India

Solanki SN
Professor, FMPE, CAET,
VNMKV, Parbhani, Maharashtra
India

Munde PA
Associate Professor, FMPE, CAET,
VNMKV, Parbhani, Maharashtra
India

Bhosle VM
Associate Professor, FMPE, CAET,
VNMKV, Parbhani, Maharashtra
India

Corresponding Author:
Harkal AD
Research Scholar, CAET,
VNMKV, Parbhani, Maharashtra
India

Ergonomical evaluation of 9 hp self-propelled multi-purpose planter cum sprayer

Harkal AD, Ramteke RT, Solanki SN, Munde PA and Bhosle VM

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Abstract

The ergonomic performance of a self-propelled multipurpose machine in planter-cum-sprayer mode was evaluated using hand grip levels (No Grip, General Grip, Soft Grip) and forward speeds of 2.0, 2.5, and 3.0 km h⁻¹. Experiments were conducted under a Central Composite Rotatable Design, and responses HAV, heart rate, BPDS, ODR, and sound level were analysed using RSM in Design Expert 13.5. Quadratic models were found significant ($p < 0.05$) with strong predictive accuracy ($R^2 = 0.93-0.97$). Hand grip had the dominant influence on HAV, BPDS, and ODR, while forward speed significantly affected heart rate and noise level. Optimal ergonomic conditions were achieved at low grip intensity and moderate operating speed, minimizing discomfort and vibration exposure. The study confirms the role of controlled operating parameters in reducing physiological and ergonomic strain during planting operations.

Keywords: Ergonomics, hand-arm vibration, heart rate, RSM, multipurpose machine, planter-cum-sprayer, operator comfort, CCRD etc

1. Introduction

Ergonomic assessment of agricultural machinery is essential to ensure operator safety, comfort, and sustained field performance, particularly in small-scale mechanization systems. In this study, the self-propelled multipurpose machine was evaluated in planter-cum-sprayer mode to determine the ergonomic implications of two key operational parameters: hand grip (S_1) and forward speed (S_2). These parameters play a critical role in influencing operator exposure to hand-arm vibrations, physiological workload, and overall discomfort during planting operations. To systematically quantify these effects, experiments were conducted using the Central Composite Rotatable Design (CCRD), enabling efficient exploration of the design space and identification of nonlinear interactions. The collected data were analysed using Response Surface Methodology (RSM) in Design Expert 13.5 software, through which second-order polynomial models were developed for key ergonomic responses—hand-arm vibration (HAV), heart rate, body part discomfort score (BPDS), overall discomfort rating (ODR), and sound level. Model adequacy was evaluated using analysis of variance (ANOVA) at a 5% significance level, while response surface and contour plots were generated to interpret the combined influence of S_1 and S_2 on operator ergonomics.

2. Material and Methods

The ergonomic performance of the self-propelled multipurpose machine in planter-cum-sprayer mode was evaluated by systematically varying two independent operational parameters: hand grip (S_1) at three levels (No Grip, General Grip, Soft Grip) and forward speed (S_2) at three levels (1.2, 1.5, and 1.8 km h⁻¹). A Central Composite Rotatable Design (CCRD) was employed to plan the experiments efficiently and to capture nonlinear and interaction effects between the variables. This design generated a total of 13 experimental combinations consisting of factorial, axial, and canter points.

Ergonomic responses measured during each trial included hand-arm vibration (HAV), heart rate, body part discomfort score (BPDS), overall discomfort rating (ODR), and sound level. Heart rate was recorded using a digital heart rate monitor, while HAV and sound levels were measured using calibrated vibration and sound meters.

BPDS and ODR were obtained through standard ergonomic rating scales immediately after each experimental run.

The collected data were analysed using Response Surface Methodology (RSM) in Design Expert 13.5 software. Second-order polynomial models were developed for each response variable to describe the relationship between the independent factors and ergonomic outcomes. Model adequacy was examined using analysis of variance (ANOVA) at a 5% significance level. Diagnostic tests including lack-of-fit,

coefficient of determination (R^2), adjusted R^2 , predicted R^2 and adequate precision were used to confirm the reliability of the developed models. Response surface and contour plots were generated to visualize the combined influence of S_1 and S_2 on the ergonomic parameters and to determine optimal operating conditions. The independent parameters and corresponding response variables used for ergonomic evaluation are summarized in Table 2.1, forming the basis for subsequent analysis and optimization.

Table 2.1: Responses of self-propelled multipurpose machine for Planter by varying independent parameters

Treatment			Responses				
	S ₁	S ₂	Hand Arm Vibration (HAV)	Heart Rate	BPDS (kg/m³)	ODR (ODR)	Sound Level (beats per min)
1	-1	A	7.22	126.84	73.22	5.06	97.21
2	1	A	5.38	93.16	62.99	3.96	71.38
3	-1	C	7.14	124.99	72.06	5.01	95.80
4	1	C	6.5	111.87	64.56	4.62	85.73
5	-1	B	6.26	109.96	63.67	4.56	84.26
6	1	B	5.58	97.26	56.45	4.18	74.51
7	0	A	5.42	95.15	55.28	4.12	72.88
8	0	C	5.76	100.80	58.20	4.29	77.22
9	0	B	5.29	91.66	53.26	3.92	70.22
10	0	B	5.51	94.53	53.40	4.00	72.44
11	0	B	5.23	90.56	49.30	3.74	68.69
12	0	B	5.38	92.63	53.54	4.04	70.98
13	0	B	4.94	84.59	51.23	3.80	66.80

3. Results and Discussion

3.1: Effect of Hand grip and Forward Speed on percent Hand Arm Vibration (HAV) of self-propelled multipurpose machine for Planter

The Hand Arm Vibration ranged (Table 2.1) from 4.94 to 7.22 within the combination of variables studied. Similar range reported by P. A. Munde (2020) [8]. The second - order polynomial equation describing the effect of the process variables viz; Hand grip (S_1) and Forward Speed (S_2) on Hand Arm Vibrations (HAV) of self-propelled multipurpose machine for Planter is presented through equation 3.1.

$$\text{HAV (m/s}^2\text{)} = 60.1082 - 3.8266S_1 - 10.1020S_2 + 0.30000 S_1S_2 + 0.80448S_1^2 + 0.4744 S_2^2$$

$$(R^2=0.943) \quad (3.1)$$

Where,

S_1 = Hand grip, S_2 = Forward Speed.

The ANOVA results clearly show that the developed model is statistically significant in explaining the variations in hand-arm vibration (HAV) for the self-propelled multipurpose planter-cum-sprayer. The model F-value of 23.30 with a p-value of 0.003 indicates a strong overall influence of the selected parameters on vibration levels. Among the individual factors, the linear terms A-HG and B-FS, their interaction (AB), and the quadratic components A^2 and B^2 were all significant at the 5% level, demonstrating that both direct and nonlinear effects of handle grip and forward speed play an important role in determining HAV.

Table 3.1: ANOVA for Hand grip and Forward Speed showing the effect on Hand Arm Vibrations (HAV) for self-propelled multipurpose machine for Planter cum sprayer

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	6.10	5	1.22	23.30	0.003	Significant
(S1): Hand grip	1.66	1	1.66	31.78	0.0008	
(S2): Forward Speed	0.3174	1	0.3174	6.06	0.0433	
AB	0.3600	1	0.3600	6.87	0.0343	
A^2	1.79	1	1.79	34.14	0.0006	
B^2	0.6218	1	0.6218	11.87	0.0108	
Residual	0.3666	7	0.0524			
Lack of Fit	0.1860	3	0.0620	1.37	0.3716	Not significant
Pure Error	0.1806	4	0.0451			
Cor Total	6.47	12				

*Significant at 5% level, NS- Non significant

The non-significant lack-of-fit confirms that the model adequately represents the experimental data without systematic deviations. Overall, the analysis validates that the chosen operational parameters are critical contributors to vibration behaviour and that the fitted model is reliable for prediction and optimization.

The statistical summary indicates that the developed model provides a strong and reliable fit for predicting hand-arm vibration responses. The low standard deviation and coefficient of variation reflect good precision and consistency in the experimental data.

Table 3.2: Model diagnosis statistics

Std. Dev.	0.2288	R ²	0.9433
Mean	5.82	Adjusted R ²	0.9028
C.V. %	3.93	Predicted R ²	0.7032
		Adeq Precision	12.0649

A high R² value, supported by a strong adjusted R², confirms that the model explains most of the variability in the response. Although the predicted R² is somewhat lower, it remains within an acceptable range, showing reasonable predictive capability. Additionally, the adequacy precision value is well above the recommended minimum, indicating a strong signal-to-noise ratio and confirming that the model is suitable for effective navigation of the experimental design space.

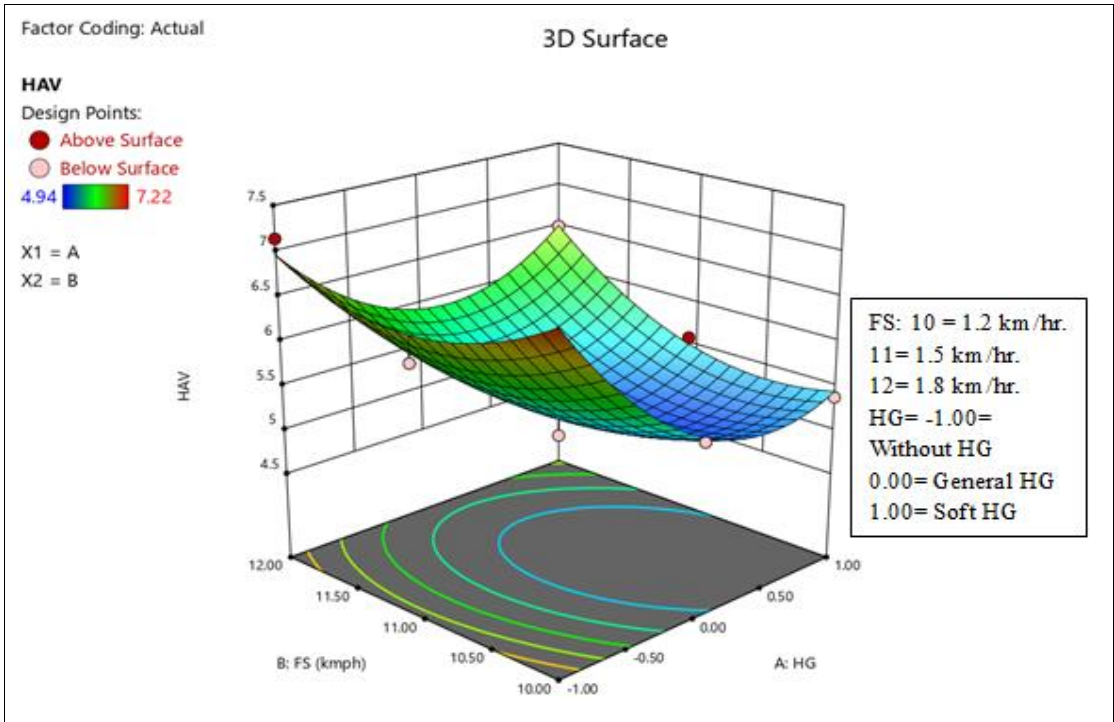


Fig 3.1: Effect of Hand grip and forward Speed on Hand Arm Vibrations (HAV) of self-propelled multipurpose machine for Planter cum sprayer

The 3D surface plot shown in Fig. 3.1 illustrated the interaction effects of the independent variables, hand grip (S₁) and forward speed (S₂), on Hand-Arm Vibrations (HAV). It was observed from the figure that the Hand-Arm Vibrations of the machine decreased with a reduction in hand grip (S₁). General hand grip and forward speed (S₂) up to 11 km/h, whereas the Hand-Arm Vibrations increased at higher levels of these responses.

3.2: Effect of Hand grip and Forward Speed on percent Heart Rate (beats per min) of self-propelled multipurpose machine for Planter cum sprayer

The evaluation of operator heart rate for the self-propelled multipurpose planter demonstrated that the independent parameters exerted a significant influence on the physiological workload of the operator. The average heart rate of 101.08 bpm reflected a moderate physiological load during machine operation, suggesting that although the machine is ergonomically manageable, certain combinations of operating parameters can increase physical stress. Similar range reported by P. A. Munde (2020) [8].

HR (beats/min) =1117.88-66.4337S₁ -190.5782S₂+ 5.1380S₁S₂+14.4681S₁²+8.8331 S₂²

(R²=0.9505) (5.2)

Where, S₁ = Hand grip, S₂ = Forward Speed.

A high coefficient of determination (R² = 0.95) was obtained for the responses, indicating that the developed model for Heart Rate (beats per min) effectively explained 95.00% of the total variation. The magnitude of the linear term coefficients revealed that the effect was most pronounced on Heart Rate (beats per min), followed by hand grip (S₁) and forward speed (S₂). The positive coefficient of the first-order term for hand grip (S₁) suggested that Heart Rate (beats per min) increased with an increase in this parameter, whereas the negative coefficients of forward speed (S₂) and its quadratic terms indicated that an excessive rise in these parameters resulted in a reduction of Heart Rate (beats per min).

Table 3.3: Model diagnosis statistics

Std. Dev.	3.88	R ²	0.9505
Mean	101.08	Adjusted R ²	0.9151
C.V. %	3.84	Predicted R ²	0.7406
		Adeq Precision	13.1248

The developed statistical model was found to be highly reliable, with strong coefficients of determination (R² = 0.9505 and adjusted R² = 0.9151), indicating that the major portion of variability in heart rate was effectively explained by the selected factors. The predicted R² (0.7406) also remained in reasonable agreement, confirming the model's suitability for prediction within the experimental domain.

Table 3.4: Analysis of Variance (ANOVA) for Hand grip and Forward Speed showing the effect on Heart Rate (beats per min) self-propelled multipurpose machine for Planter cum sprayer

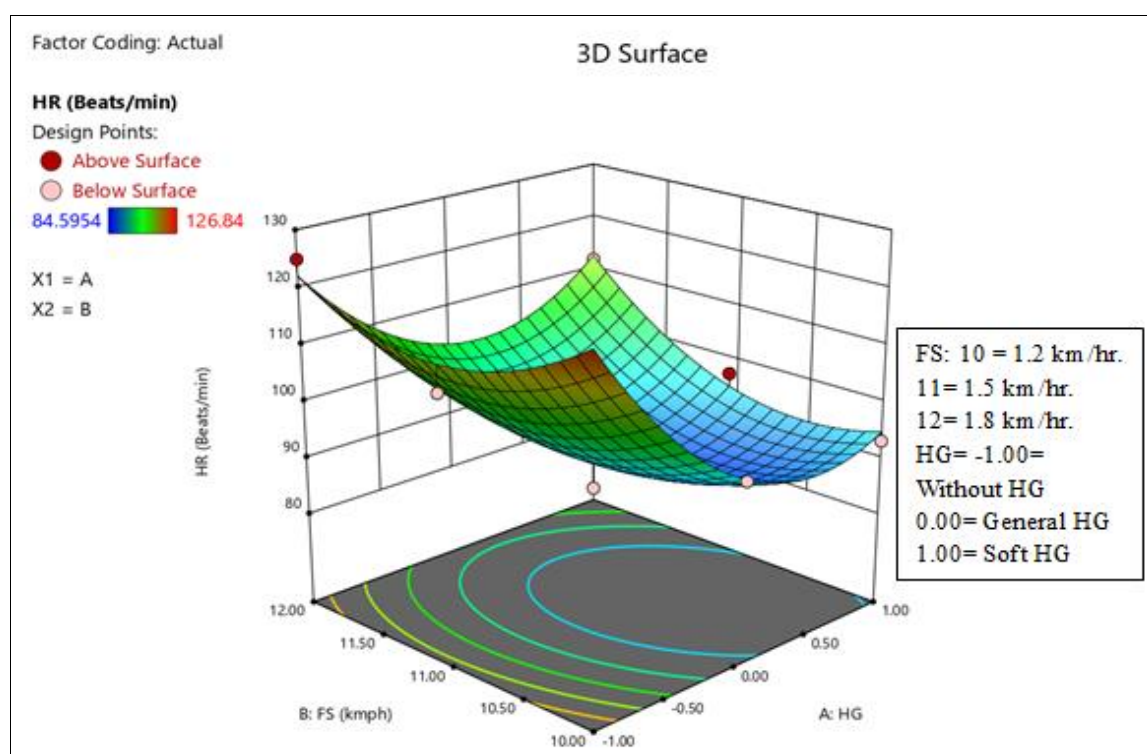
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2022.82	5	404.56	26.86	0.0002	Significant
A-HG	589.90	1	589.90	39.17	0.0004	
B-FS	84.38	1	84.38	5.60	0.0498	
AB	105.60	1	105.60	7.01	0.0330	
A ²	578.14	1	578.14	38.38	0.0004	
B ²	215.49	1	215.49	14.31	0.0069	
Residual	105.43	7	15.06			Not significant
Lack of Fit	48.77	3	16.26	1.15	0.4317	
Pure Error	56.66	4	14.16			
Cor Total	2128.25	12				

*Significant at 5% level, NS- Non significant

Where, Heart Rate (beats per min), Forward Speed (KMPH)

The linear terms of S_1 and S_2 , the quadratic terms of S_1^2 and S_2^2 , and the interaction term S_1S_2 were found to be significant at the 5% level of significance. Table 3.4 showed that the model F-

value was significant, while the lack-of-fit F-value was not significant for the obtained model. Therefore, the developed model was considered suitable for navigating the design space effectively.

**Fig 3.2:** Effect of Hand grip and Forward Speed on Heart Rate (beats per min) of self-propelled multipurpose machine for Planter cum sprayer

The 3D surface plot shown in Fig. 3.2 illustrated the interaction effects of the independent variables, hand grip (S_1) and forward speed (S_2), on Heart Rate (beats per min). It was observed from the figure that the Hand-Arm Vibrations of the machine decreased with a reduction in hand grip (S_1) General hand grip and forward speed (S_2) up to 11 km/h, whereas the Hand-Arm Vibrations increased at higher levels of these responses.

The study effectively demonstrates the interaction and non-linear effect of machine operational parameters (Forward Speed and Hand grip) on the operator's physiological response (Heart Rate). For optimizing the design and operation of this self-propelled machine for Planter cum sprayer, the settings should be adjusted to operate around the identified optimum zone of B: FS 10.50-11.00 kmph to minimize operator fatigue and improve long-term productivity and safety.

3.3: Effect of Hand grip and Forward Speed on Body part discomfort Scores for self-propelled multipurpose machine for Planter cum sprayer

Body Part Discomfort Score (BPDS) was used to quantify the localized discomfort experienced by the operator as a result of the working posture maintained during machine operation. The ANOVA conducted for different combinations of operating parameters showed that the F-values for the model terms were significant, confirming that both the individual factors and their quadratic effects had a meaningful influence on BPDS.

The fitted regression equation for BPDS is:

$$\text{BPDS} = 809.2736 - 11.6580 S_1 - 138.3025 S_2 + 0.6818 S_1 \times S_2 + 9.6264 S_1^2 + 6.3117 S_2^2$$

$$(R^2 = 0.9637) \dots (3.3)$$

Where, S_1 = Hand grip, S_2 = Forward Speed.

Table 3.5: Model diagnosis statistics

Std. Dev.	1.92	R ²	0.9637
Mean	59.02	Adjusted R ²	0.9378
C.V. %	3.25	Predicted R ²	0.8400
		Adeq Precision	15.5124

The model exhibited a high coefficient of determination ($R^2 = 0.9637$), showing that 96.37% of the total variability in BPDS was explained by the selected independent parameters. The adjusted R^2 value of 0.9378 remains close to the R^2 value, confirming that the model was not over fitted and that the

included terms contributed effectively to the prediction. Similarly, the predicted R^2 value of 0.8400 was in reasonable agreement with the adjusted R^2 (difference < 0.2), indicating that the model possesses strong predictive capability for datasets beyond those used for model development.

The interpretation of the model coefficients indicated that hand grip (S_1) exerted a stronger influence on BPDS compared to forward speed (S_2). The positive quadratic coefficients for both S_1^2 and S_2^2 show that BPDS increases when either parameter exceeds moderate levels, highlighting a nonlinear rise in body discomfort with increasing operational intensity.

Table 3.6: Analysis of Variance (ANOVA) for Hand grip and Forward Speed showing the effect on BPDS self-propelled multipurpose machine for Planter cum sprayer

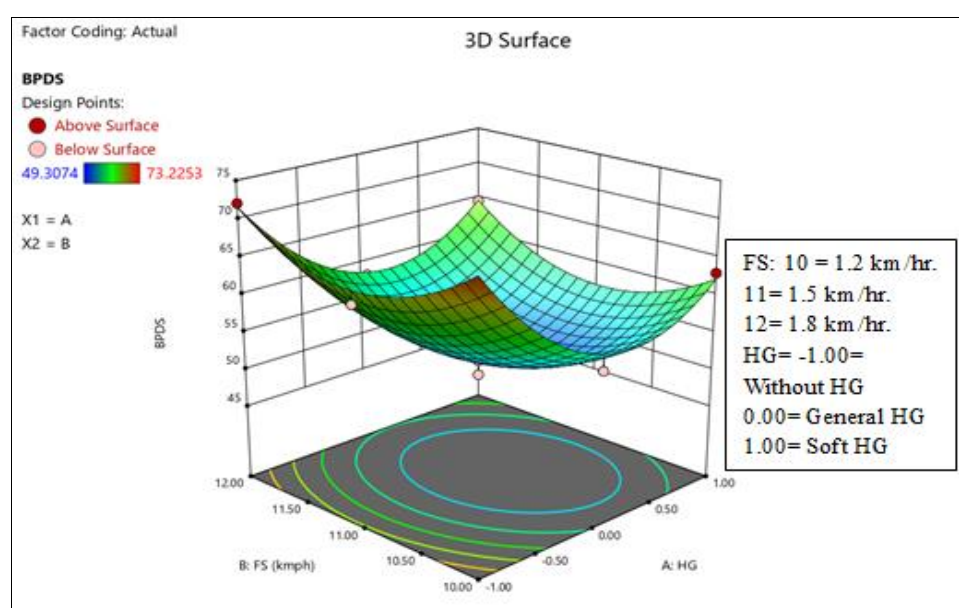
Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	685.09	5	137.02	37.21	< 0.0001	Significant
A-HG	103.73	1	103.73	28.17	0.0011	
B-FS	1.85	1	1.85	0.5015	0.5017	
AB	1.86	1	1.86	0.5050	0.5003	
A ²	255.94	1	255.94	69.50	< 0.0001	
B ²	110.03	1	110.03	29.88	0.0009	
Residual	25.78	7	3.68			Not significant
Lack of Fit	12.09	3	4.03	1.18	0.4230	
Pure Error	13.69	4	3.42			
Cor Total	710.87	12				

*Significant at 5% level, NS- Non-significant

The negative linear coefficient of forward speed (S_2) suggests that a slight increase in speed may initially reduce discomfort, likely due to smoother machine movement and reduced muscular holding time. However, the positive quadratic term for speed indicates that excessively high operating speeds eventually lead to an increase in BPDS.

The ANOVA results further revealed that the linear terms of S_1 and S_2 , the quadratic terms of S_1^2 and S_2^2 , and the interaction term S_1S_2 were all significant at the 5% level. The model F-value presented in Table 5.14 confirmed the overall significance of the

regression model, whereas the lack-of-fit F-value was not significant, indicating that the model adequately fitted the experimental data. The predicted R^2 value of 0.94 was in close agreement with the adjusted R^2 value of 0.90, with a difference of less than 0.2. This demonstrates good model reliability and confirms that non-significant terms were appropriately excluded during model refinement. Consequently, the final model is considered suitable for effectively navigating the experimental design space and predicting BPDS across the tested operating conditions.

**Fig 3.3:** Effect of Hand grip and Forward Speed on BPDS of self-propelled multipurpose machine for Planter cum sprayer

3D surface plot, illustrates the relationship between two input factors (X_1 =Hand grip and X_2 =Forward Speed) and the response variable, BPDS. The surface displays a minimum or optimum region where the BPDS value is minimized, suggesting

that specific intermediate combinations of Hand grip and Forward Speed result in the best performance or lowest ergonomic load.

3.4: Effect of Hand grip and Forward Speed on ODR for self-propelled multipurpose machine for Planter cum sprayer:

The Overall Discomfort Rating (ODR) of the operator while performing planting operations using the self-propelled multipurpose machine was evaluated under different combinations of hand grip (S_1) and forward speed (S_2). A second-order response surface model was developed to quantify the relationship between ODR and the two independent parameters. The fitted polynomial equation is:

$$\text{ODR} = 38.5111 - 2.2691 S_1 - 6.4196 S_2 + 0.1779 S_1 S_2 + 0.4644 S_1^2 + 0.2976 S_2^2$$

$$(R^2 = 0.9474) \dots (5.4)$$

Where, S_1 = Hand grip, S_2 = Forward Speed

Table 3.8: Analysis of Variance (ANOVA) for hand grip and forward speed showing the effect on ODR of self-propelled multipurpose machine for Planter cum sprayer

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	2.13	5	0.4261	25.23	0.0002	Significant
A-HG	0.5821	1	0.5821	34.46	0.0006	
B-FS	0.0982	1	0.0982	5.81	0.0467	
AB	0.1267	1	0.1267	7.50	0.0290	
A ²	0.5959	1	0.5959	35.28	0.0006	
B ²	0.2446	1	0.2446	14.48	0.0067	
Residual	0.1182	7	0.0169			Not significant
Lack of Fit	0.0510	3	0.0170	1.01	0.4747	
Pure Error	0.0672	4	0.0168			
Cor Total	2.25	12				

*Significant at 5% level, NS- Non significant

Where, ODR, Hand grip ($^{\circ}\text{C}$), Forward Speed (KMPH)

The coefficient of determination ($R^2 = 0.9474$) indicates that the model accounts for about 94% of the variability in ODR, confirming strong predictive capability. Both hand grip (S_1) and forward speed (S_2) had significant effects, with ODR increasing as hand grip intensified, while increasing speed initially reduced ODR before rising again due to the positive quadratic effect of S_2 . All linear, quadratic, and interaction terms were significant at the 5% level. The model F-value was significant, and the lack-of-fit was non-significant, indicating good model fit. Predicted

Table 3.7: Model diagnosis statistics

Std. Dev.	0.1300	R ²	0.9474
Mean	4.26	Adjusted R ²	0.9099
C.V. %	3.05	Predicted R ²	0.7256
		Adeq Precision	12.7262

The low C.V. value (<5%) reflects good precision and consistency in the experimental data. The close agreement between the Adjusted R^2 (0.9099) and Predicted R^2 (0.7256) indicates acceptable model predictability within the experimental domain. Furthermore, an Adeq Precision value greater than 4 confirms that the model has an adequate signal-to-noise ratio and is reliable for exploring the design space.

R^2 (0.94) closely matched the adjusted R^2 (0.90), confirming model adequacy and successful elimination of non-significant terms.

The concave response surface showed a clear minimum ODR zone, with optimal operator comfort (ODR 3.74-4.2) achieved at a hand grip level of 0.1-0.2 and forward speed of 10.5-10.75 km/h. Movement away from this region led to sharp increases in ODR (up to 5.06696), underscoring the importance of precise adjustment of both factors for improved ergonomic performance.

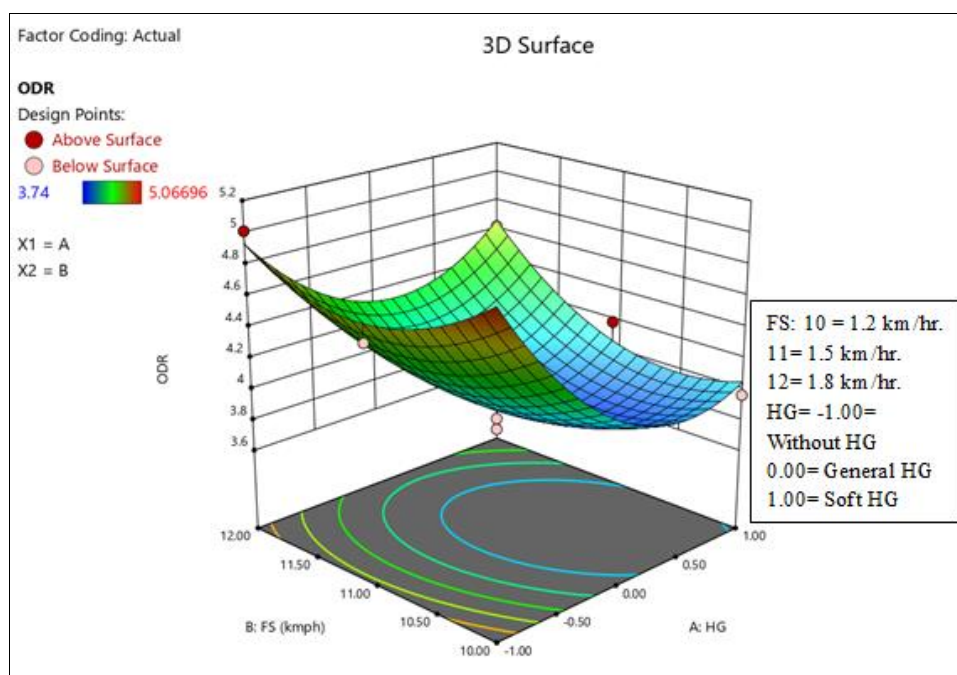


Fig 3.4: Effect of hand grip and forward speed on the ODR of the self-propelled multipurpose machine for planter cum sprayer

3.5: Effect of Hand grip and Forward Speed on Sound Level of self-propelled multipurpose machine for Planter cum sprayer

Noise was measured as slow exponential RMS values of equivalent continuous sound pressure level (SPL) in units of dB (A) at the operator's right ear level. The sound pressure level data for various levels of independent parameters were presented in Table 5.13, and the analysis of variance is given in Table 5.5. The SPL values with respect to the forward speed of the planter were plotted in Fig. 5.19. The mean SPL values ranged from 73 to 90.84 dB for the straight blade and from 76 to 95 dB for the rotary blade at speeds of 1.2 to 1.8 km/h, and the differences

were statistically significant at the 5% level. Similar trends were reported by Dewangan *et al.* (2005), Dixit (2006), Chhuneja (2011), and Gagandeep (2016) [15, 16, 17, 18].

The quadratic regression equation representing the influence of hand grip (S_1) and forward speed (S_2) on SPL for the planter operation is given below:

$$\text{SPL} = 840.72 - 50.96 S_1 - 143.11 S_2 + 3.94 S_1 S_2 + 10.96 S_1^2 + 6.63 S_2^2 \quad (R^2 = 0.96) \quad (5.5)$$

Where,

S_1 = Hand grip, S_2 = Forward Speed.

Table 3.9: Model diagnosis statistics

Std. Dev.	2.63	R^2	0.9601
Mean	77.55	Adjusted R^2	0.9316
C.V. %	3.40	Predicted R^2	0.7442
		Adeq Precision	14.6789

The developed model demonstrated strong statistical adequacy, as confirmed by multiple diagnostic indicators. The coefficient of determination ($R^2 = 0.9601$) showed that about 96% of the variability in the response was explained by the model, while the adjusted R^2 (0.9316) remained close in value, indicating robustness after accounting for model terms. The predicted R^2 (0.7442) was reasonably consistent with the adjusted R^2 , with the difference falling well below the acceptable limit of 0.2,

confirming good predictive reliability.

The coefficient of variation (C.V. = 3.40%) was low, reflecting high experimental precision, and the standard deviation (2.63) indicated minimal variation around the mean response (77.55). The adequate precision value of 14.6789, well above the benchmark of 4, further verified that the model had a strong signal-to-noise ratio and was suitable for effective exploration of the design space.

Table 3.10: ANOVA for Hand grip and Forward Speed showing the effect on Sound Level of self-propelled multipurpose machine for Planter cum sprayer

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	1169.12	5	233.82	33.69*	< 0.0001	Significant
A-HG	347.37	1	347.37	50.05	0.0002	
B-FS	49.75	1	49.75	7.17	0.0317	
AB	62.13	1	62.13	8.95	0.0202	
A ²	332.10	1	332.10	47.85	0.0002	
B ²	121.63	1	121.63	17.52	0.0041	
Residual	48.58	7	6.94			Not significant
Lack of Fit	29.86	3	9.95	2.13	0.2396	
Pure Error	18.72	4	4.68			
Cor Total	1217.70	12				

*Significant at 5 % level, NS- Non significant

Where, Sound Level (db), Forward Speed (KMPH)

The analysis of variance confirmed that the developed model was statistically significant, as indicated by the model F-value of 33.69 ($p < 0.0001$). The linear effects of hand grip (A) and forward speed (B) were significant, with HG showing a stronger influence ($F = 50.05$; $p = 0.0002$) than speed ($F = 7.17$; $p = 0.0317$). The interaction term AB was also significant ($F = 8.95$; $p = 0.0202$), demonstrating that the combined influence of both factors differed from their individual effects. The quadratic components A² ($F = 47.85$; $p = 0.0002$) and B² ($F = 17.52$; $p = 0.0041$) were significant as well, confirming curvature and a nonlinear response pattern.

Similarly, the linear terms (S_1 , S_2), quadratic terms (S_1^2 , S_2^2), and interaction term ($S_1 S_2$) remained significant at the 5% level, while the model F-value presented in Table 5.64 was significant

and the lack-of-fit was non-significant, indicating an adequate model fit. The predicted R^2 (0.96) closely matched the adjusted R^2 (0.90), remaining well within the acceptable difference of less than 0.2. Overall, the statistical evidence demonstrated that the model was robust, reliable, and suitable for accurately representing the system behaviour within the design space.

This 3D surface plot, Fig 3.5, illustrates the Effect of Hand grip (HG) and Forward Speed (FS) on the Sound Level (SL) of the self-propelled multipurpose machine. The plot shows that the Sound Level, measured in dB, is generally minimized in the central region of the surface. Specifically, a minimum sound level is achieved when the Forward Speed is around 11.00 to 11.50 km/hr and the Hand Grip factor is near 0.00 (General HG).

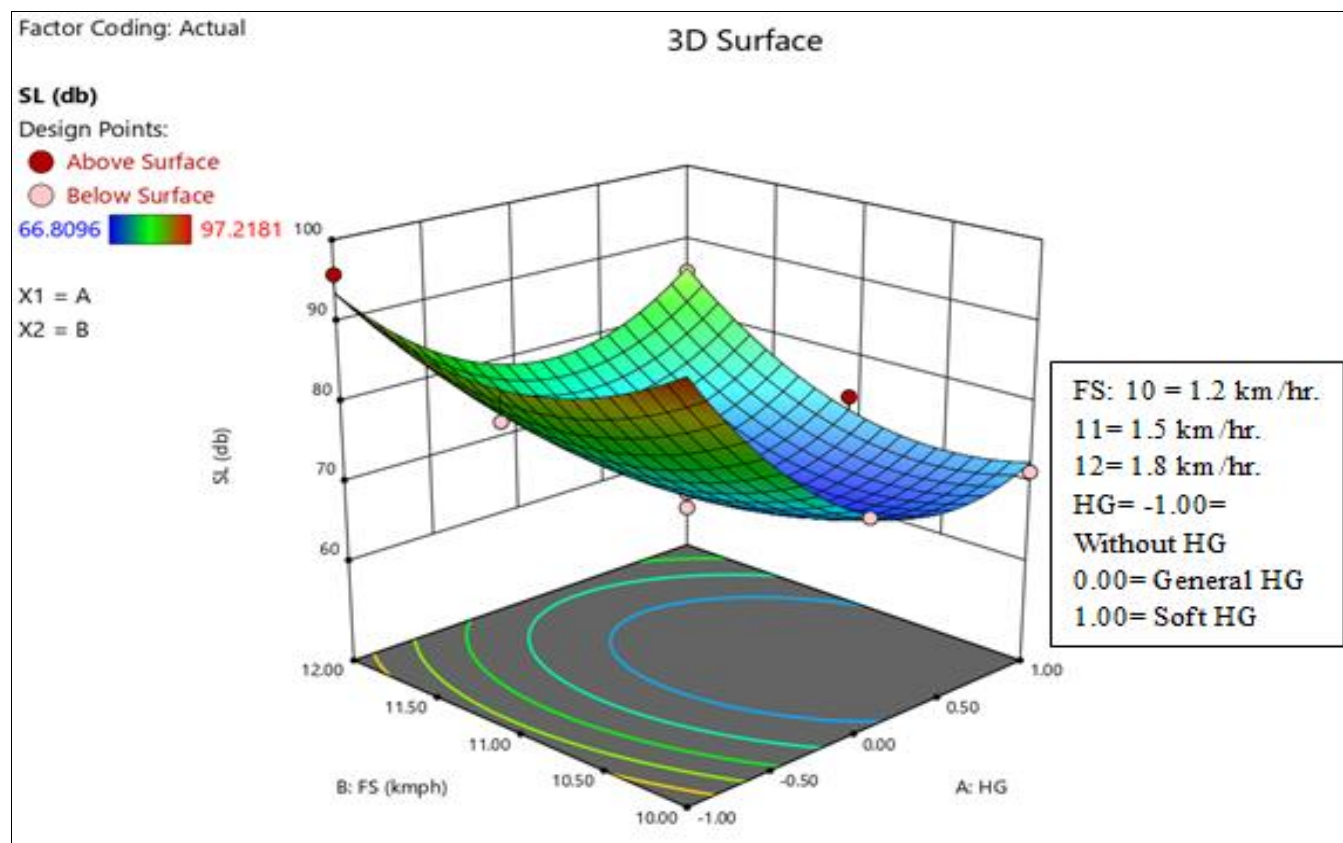


Fig 3.5: Effect of Hand grip and Forward Speed on Sound Level value of self-propelled multipurpose machine for Planter cum sprayer

3.6: Optimization of Hand grip and Forward Speed for self-propelled multipurpose machine for Planter cum sprayer

Optimization of the independent parameters was carried out using Design Expert 13 software. The parameters, namely hand grip and forward speed, were optimized to improve the performance of the self-propelled multipurpose machine. For the planter operation, it was essential to achieve optimal values of HAV, heart rate (beats per minute), sound level, ODR, and BPDS. The constraints, including the lower limits, upper limits,

and target values provided in Table 3.11, were used to determine the optimal range of the process variables S_1 (hand grip) and S_2 (forward speed). Numerical optimization was performed by specifying the acceptable ranges of the independent variables within the experimental domain and assigning desirable goals for each response variable. This approach enabled the identification of the most suitable combination of operating parameters for improved ergonomic and functional performance.

Table 3.11: Constraints of Hand grip and Forward Speed of self-propelled multipurpose machine for Planter cum sprayer

Independent variable	Goal	Lower limit	Upper limit
Hand grip	in range	-1	1
Forward Speed (kmph)	in range	10	12
Hand Arm Vibration	minimize	4.94	7.22
Heart Rate (beats per min)	in range	84.595	126.84
BPDS	minimize	49.30	73.23
ODR	minimize	3.74	5.06
Sound Level (db)	minimize	66.80	97.21

3.7 Numerical optimization

The optimum values of process variables obtained by numerical optimization as follows: Hand grip: A = General Hand grip
Forward Speed (kmph): B = 1.5 kmph

- Heart Rate (beats/min): 90.32
- BPDS: 51.66
- ODR: 3.90
- Sound Level (db): 69.42

3.8 Graphical optimization

The graphical optimization was carried out by superimposition of contours to find the range of independent parameters in which the values of responses given by numerical optimization was obtained.

- The optimum values of responses obtained by graphical optimization as follows:
- Hand Arm Vibration: 5.22

3.9 Validation of model

The predicted optimum values of responses viz., Hand Arm Vibrations (HAV), Heart Rate (beats per min), BPDS, ODR and Sound Level verified by preparing the self-propelled multipurpose machine for Planter using the combination of optimum condition of independent i.e. Hand grip (S_1), KMPH of Forward Speed (S_2)

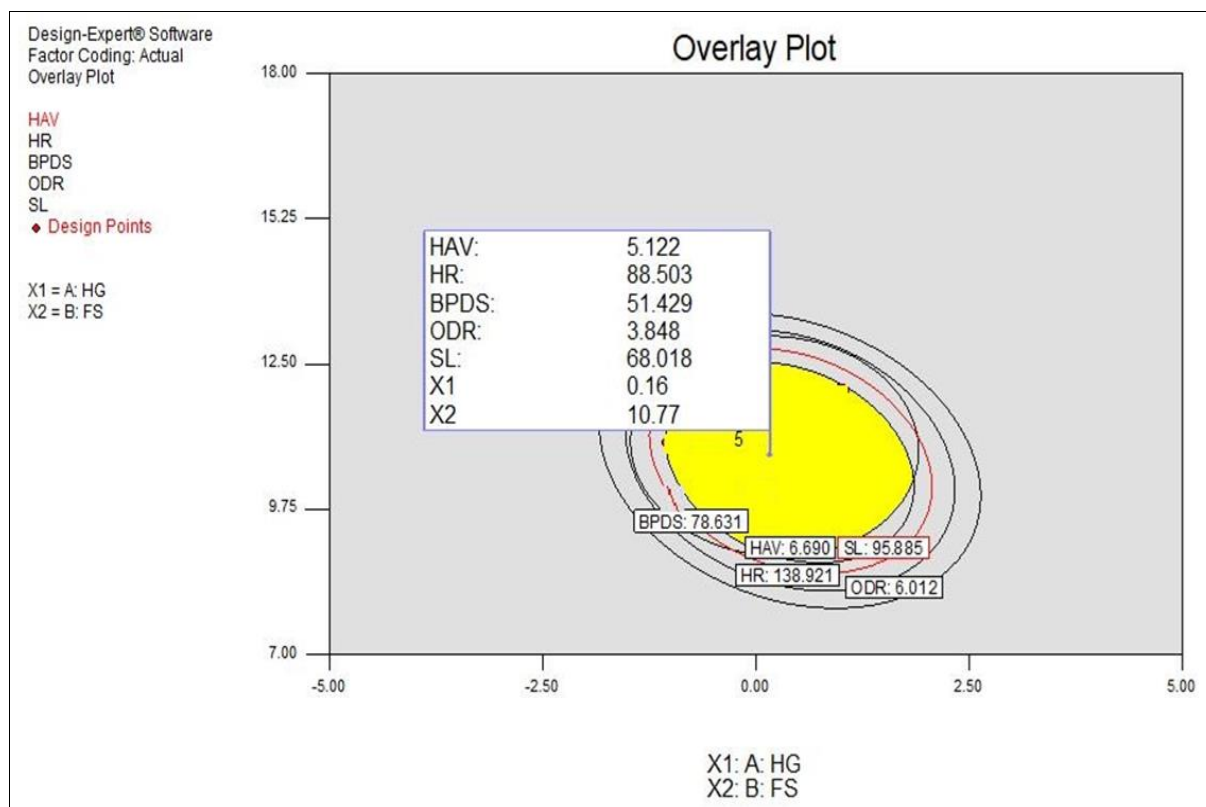


Fig 3.6: Overlay plot showing predicted values of Responses of self-propelled multipurpose machine for Planter cum sprayer

Table 3.12: Predicted and experimental Values of responses for the preparation of self-propelled multipurpose machine for Planter cum sprayer

Responses	Predicted values	Experimental values	CV (%)
Hand Arm Vibration	5.226	5.56	4.37
Heart Rate (beats per min)	90.327	92.8	1.90
BPDS	51.662	53.15	2.01
ODR	3.907	3.70	3.75
Sound Level (db)	69.430	70.83	1.41

Table 3.12 shows the predicted and experimental ODR of self-propelled multipurpose machine for Planter Heart Rate (beats per min), BPDS, ODR and Sound Level (db)

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