DESIGNING AND OPTIMIZATION OF A MOBILE CROP RESIDUE DISINTEGRATOR BY USING BOX BEHNKEN RSM METHOD

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ABSTRACT

The most commonly used designs to determine response surfaces are the full and fractional factorial designs and the more complex central composite, Box–Behnken, Doehlert and mixture designs. Although the factorial designs can be used to determine simple response surfaces that are linear in all of the investigated factors, they are normally used to determine which experimental factors are the most important to investigate and which factors do not significantly affect the experimental results. The more important the interaction term, the greater is the degree of twisting the planar response surface experiences. If the linear model is not sufficient to represent the experimental data adequately, more experiments can be performed in addition to those of factorial design. The Box–Behnken and Doehlert designs can also be used to determine these kinds of response surfaces and optimize chromatographic factors such as temperature, column characteristics and flow rates. Mixture designs are used to vary proportions of mixture ingredients such as the solvent proportions of a mobile phase

Key words: Box–Behnken Doehlert, Fractional Factorial Designs, Mixture Designs

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1. INTRODUCTION

The present study of design and development of a crop residue mobile disintegrator machine. The main objectives of the research work were to develop a suitable size tractor operated crop residue disintegrator and to study the performance of the machine in actual field conditions with utilizing the optimized blade angle. The present machine was designed and developed by considering the different parameters. On the basis of theoretical considerations and assumptions made on different parameter for selection and development of components of mobile disintegrator machine various reviews taken in account of in the development procedure. As Accordingly the various parts are developed and selected from the market during the development procedure. For optimization of design the cutting blade angle with different speed and load plays a vital role. For this the analysis was made on the combinations of blade angels, impact load and cutting speed and observed the responses on actual force, cutting efficiency and collection efficiency by utilizing the trial version of Design Expert 10.0.2 software for experimental design. The factorial Box-Behnken design matrices method was selected for optimized solution of the blade angle with 17 runs with three variables. By using this software the optimized solution of the blade angle with an impact load at a speed was detrain. Due to this an optimized blade was used for the final prototype development and to Observed the field performance on large field.

1.1. BOX-BEHNKEN DESIGNS

Box-Behnken designs constitute an alternative to central composite designs [20]. They are a class of rotatable or nearly rotatable second-order designs based on three-level incomplete factorial designs. Fig. 1 shows the Box-Behnken design for three factors, corresponding to the coded values listed in Table 1. It is easy to see that this design consists of three parts of four runs. Within each part, two factors are arranged in a full two-level design, while the level of the third factor is set at zero. The points lie on the surface of a sphere centered at the origin of the coordinate system and tangential to the midpoint of each edge of the cube. Compared to the central composite design, this design has some advantages. The three-factor Box-Behnken design requires only 12 runs plus the replicates at the center point, whereas its central composite counterpart has 14 non-center points. In general the number of experimental points is given by $2k(k-1) + C0$. Also, each factor is studied at only three levels, an important feature in some experimental situations, as we have already mentioned. On the other hand, using $\alpha=1$ in a central composite design also results in three levels for each factor. In most real applications these differences are probably not decisive in determining which design to use, at least for this number of factors. However, since Box-Behnken designs do not contain combinations where all the factors are at their higher or lower levels, they may be useful in avoiding experiments under extreme conditions, for which unsatisfactory results might occur. Conversely, they are not indicated for situations in which we would like to know the responses at the extremes, that is, at the vertices of the cube. Box-Behnken designs for four and five factors can be arranged in orthogonal blocks, as shown in Table 1. In this table, each $(\pm 1, \pm 1)$ combination within a row represents a full 2^2 design. Dashed lines separate the different blocks. Because of the block orthogonality, the second-order model can be augmented to include block effects without affecting the parameter estimates, that is, the effects themselves are orthogonal to the block effects. This

orthogonal blocking is a desirable property when the experiment has to be arranged in blocks and the block effects are likely to be large.

Figure 1 Box Behken design

Table 1 BBD coded level

Table 3
Coded factor levels for a Box-Behnken design for a three-variable system

x_1	x_2	x_3
-1	-1	0
1	-1	0
-1	1	0
1	1	0
-1	0	-1
1	0	-1
-1	0	1
1	0	1
0	-1	-1
0	1	-1
0	-1	1
0	1	1
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0

2. LITERATURE

‘Sergio Luis Costa Ferreira et. al (2007) describes fundamentals and applications of multivariate statistical techniques for the optimization of chromatographic systems. The surface response methodologies: central composite design, Doehlert matrix and Box-Behnken design are discussed and applications of these techniques for optimization of sample preparation steps (extractions) and determination of experimental conditions.

Box-Behnken designs for four and five factors can be arranged in orthogonal blocks, as shown in Table 1. In this table, each $(\pm 1, \pm 1)$ combination within a row represents a full 22 design.

M Manohar et. al (2013) have reported that the use of Box Behnken design approach is good for developing Response Surface methodology (RSM) has been adopted to express the output parameters (responses) that are decided by the input process parameters. Box-Behnken design is having the maximum efficiency for an experiment involving three factors and three levels; further, the number of experiments conducted for this is much lesser compared to a central composite design. The proposed Box-Behnken design requires 15 runs of experiment for data acquisition and modeling the response surface. Box Behnken design was successfully adopted and the experiments were designed choosing the input variables for the levels selected. With minimum

number of experiments, data was collected and the models were developed. Response Surface Models evolved for responses show the effect of each input parameter and its interaction with other parameters, depicting the trend of response.

Perincek Oguz and Colak Metin (2013) It was reported that the BBD model provided an excellent explanation of the relationship among the number of loads and the net harmonic currents. The results of experiments confirmed that the Box-Behnken experimental design can be used for the determination of loads responsibility and interactions of loads ($A \times B$, $A \times C$, $B \times C$, etc.) for the 3rd and 5th harmonic currents.

Myalowenkosi I. Sabela (2014), In this study a Box-Behnken design with fifteen runs, three independent variables (pH, concentration of NH_4Cl - NH_4OH and APDC) and three replicates at a centre point was used in this study. The experiment was randomized to reduce confounding variables by equalizing the three independent variables that have not been accounted for in the experimental design.

Ramesh rudrapati et al (2015). In this work mathematical modeling has been done by response surface method (RSM). In this study BBD with three factors, three level, and 15 runs are selected. In the BBD matrix the experiment consists of a set of points lying at the midpoint of each edge and replicated center point of multidimensional cube.

3. DATA ANALYSIS AND OPTIMIZATION

Regression analysis and analysis of variance (ANOVA) were conducted for fitting the models represented by Eq. 4.2 to examine the statistical significance of the model terms. The adequacy of the models were determined using model analysis, lack of fit test and R^2 (coefficient of determination) analysis. The lack of fit is a measure of failure of a model to represent data in the experiment domain at which at which points were not included in the regression or variations in the models cannot be accounted for by random error. If there is a significant lack of fit, as indicated by a low probability value, the response predictor is discarded. The R^2 is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit. Coefficient of variation (CV) indicates the relative dispersion of the experimental points from the prediction of the model. Response surfaces and contour plots were generated with the help of commercial statistical package, Design Expert-version 10.0.2. The numerical and graphical optimization was also performed by the same software.

4. OPTIMIZATION PERFORMANCE EVALUATION OF CROP RESIDUE MOBILE DISINTEGRATOR MACHINE

The field tests were conducted with a range of moisture content 31.16% to 34.18%. The cotton stalk density represents wider range of crop residue that was usually encountered in field conditions. The various size of cotton stalk was available in the plot while conducting the trials but the maximum size of 20.12. The size of plot has been selected to 25m x 25m for maintaining uniformity throughout all the experiment on **plot design**. Actual cutting force, cutting efficiency and collection efficiency for cotton stalk were determined under performance evaluation of mobile disintegrator machine with the variables of cutting blade angle, cutting speed, and impact load. All the experiments were conducted at Cotton Research Station, and Agronomy Deptt. plot of Dr PDKV Akola. The speed of the machine was 2.5 km/h to 3 km/h with varying speed ratios of rotor requirement. The observations for each experiment were recorded in Table 3.

Table 2 Effect of blade angle on actual cutting force required speed for cotton stalk cutting mechanism with impact load

Actual Force in N						
Cotton Stalk diameter 20mm						
	Blade Angle in Degree			Impact Load N		
Cutting speed	100	105	110	10	20	30
1600	12.5	10.23	9.41	10.23	9.41	10.63
1800	12.95	8.84	9.15	10.95	8.78	12.82
2000	10.35	9.85	9.38	8.87	10.35	9.85

From Table 2, it is depicted that the minimum cutting force required with cutting blade angel of 105^0 and was observed to be 8.84 N at, 1800rpm, In above all speed the cutting force required to cut material is less in 105^0 blade angle.

Similarly the actual cutting force to be required for the cutting of crop residue with a impact load of 30N was 10.63, 12.95 and 9.85 N at 1600, 1800, 2000 rpm were recorded . In above all speed the cutting force required to cut material is less in the impact load of 20 N

Surface plot for 1600rpm

Contour plot for 1600rpm

Surface plot 1800rpm

Contour plot for 1800rpm

Surface plot for 2000rpm

Contour plot for 1600rpm

Figure 2 Effect of blade angle on actual cutting force required speed for cotton stalk cutting mechanism with impact load.

Table 3 Effect of blade angle on cutting efficiency required speed for cotton stalk cutting mechanism with impact load

Cutting Efficiency%						
Cotton Stalk diameter 20mm						
	Blade Angle ,in Degree			Impact Load, N		
Cutting speed	100	105	110	10	20	30
1600	96.17	95.86	94.18	95.86	94.18	98.11
1800	96.92	98.38	94.9	93.18	98.58	94.9
2000	96.19	97.19	96.15	96.02	96.15	97.19

From Table 4, it is depicted that the maximum cutting efficiency required with cutting blade angel of 105^0 and was observed to be 98.38% at, 1800 rpm, also for same blade angle the cutting efficiency required it is depicted that the maximum cutting efficiency obtained to cut cotton stalk of 20 mm diameter with impact load of 20 N was 98.58 % at 1800 rpm were observed in the given table. In above all speed the maximum cutting efficiency obtained after cutting of all crop residue in the impact load of 20 N .

Surface plot 1600rpm

Contour plot 1600

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Surface plot 1800

Contour plot 1800

Surface plot 2000rpm

Contour plot 2000rpm

Figure 3 Effect of blade angle on cutting efficiency required speed for cotton stalk cutting mechanism with impact load

Table 4 Effect of blade angle on collection efficiency required speed for cotton stalk cutting mechanism with impact load

Collection Efficiency%						
Cotton Stalk diameter 20mm						
	Blade Angle in Degree			Impact Load N		
Cutting speed	100	105	110	10	20	30
1600	75.12	77.96	73.18	76.54	75.12	77.96
1800	74.98	80.8	74.18	74.95	81.35	74.84
2000	77.19	75.19	75.48	75.87	77.19	75.19

It is depicted that the maximum collection efficiency required with cutting blade angel of 105^0 and was observed to be 80.85% at, 1800 rpm, In above all speed the collection efficiency obtained after cut material is maximum in 105^0 blade angle.

It is depicted that the maximum collection efficiency obtained to cut cotton stalk of 20 mm diameter with impact load of 20 N was 81.35 % at 1800 rpm were observed in the given table 5.

In above all speed the maximum collection efficiency obtained after cutting of all crop residue in the impact load of 20 N.

Surface plot for 1600rpm

Contour plot 1600rpm

Surface plot 1800rpm

Contour plot for 1800rpm

Surface plot for 2000rpm

Contour plot 2000rpm

Figure 4 Effect of blade angle on collection efficiency required speed for cotton stalk cutting mechanism with impact load

Table 5 Annova of Annova of cutting force, cutting efficiency collection efficiency

Sr		Cutting Force,	Cutting Efficiency	Collection Efficiency
1	Model	0.001	0.0003S	0.004S
2	Lack of Fit	0.12NS	0.0158NS	0.065NS
3	R-Squared	0.94	0.96	0.92
4	Adj R-Squared	0.86	0.92	0.82
5	Std. Dev.	0.53	0.49	1.23
6	Mean	10.09	96.37	77.12

5. ANALYSIS OF VARIANCE

Regression analysis and analysis of variance (ANOVA) were conducted for fitting the models represented by Eq. 4.2 to examine the statistical significance of the model terms. The adequacy of the models were determined using model analysis, lack of fit test and R² (coefficient of determination) analysis. The lack of fit is a measure of failure of a model to represent data in the experiment domain at which at which points were not included in the regression or variations in the models cannot be accounted for by random error. If there is a significant lack of fit, as indicated by a low probability value, the response predictor is discarded. The R² is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit. Coefficient of variation (CV) indicates the relative dispersion of the experimental points from the prediction of the model. Response surfaces and contour plots were generated with the help of commercial statistical package, Design Expert-version 10.0.2. The numerical and graphical optimization was also performed by the same software ANOVA has been carried out, with the use of Design Expert-version 10.0.2. software. The results of this analysis are shown in Table 5 (in respect of acceleration of vibration) and in Table 6 (in respect of surface roughness). It is known that if the P value (significance probability value) is less than 0.05, the corresponding parameter or variable is considered to be "significant" in influencing the output response, at 95 % confidence level [29]. From Table 5, it is evident that blade angle (A) and its square combination (A²) are "most significant" in the context of the response: acceleration of vibration, as corresponding P values are zero. The square combination of work speed (C²) is also very significant as its P value is very

6. RESULTS AND ANALYSIS

Close to zero. And, individual effect of impact load (B) and its square combination (B²) are found to be significant as relevant P values are less than 0, 05. The cutting speed (C) and interactions like infeed-longitudinal feed (A x B), infeed-work speed (A x C), and longitudinal feed-work speed (B x C) do not have significant effect on vibration as their P values are more than 0.05.

6.1. Response surface plots Response surface plots are drawn based on the developed model equations [Eq. 3 for acceleration of vibration and Eq. 4 for machine These plots (and also the earlier contour plots) are generated for various combinations of the input parameters and different hold values of the third parameter(s). Few of the response surface plots are given in Figs. 2, 3, and 4 for vibration and in Figs. 5, 6, and 7 for surface roughness. Since each model has three variables, one

6.2. Response Contour Plots Contour plots are drawn based on second-order mathematical models Some representative contour plots for cutting force are shown in Figs.

2, 3, and 4 and for MACHINE in Figs. 5, 6, and 7. These response contours can help in the prediction of the responses at any zone of the experimental domain. Different shades/contrasts have been used in the contour plots, depending on lowest to largest values of the response.

6.3. Optimization of design parameters for development of straw cutting mechanism

Numerical and graphical optimization was carried out for independent design parameters of the mobile disintegrator machine to obtain the optimum blade angle with minimum cutting force requirement, to operate at maximum cutting efficiency and collection efficiency. To perform this operation, the Design-Expert software as discussed in section 4.6, was used for simultaneous optimization of the multiple responses. The desired goals for each factor and response were chosen as shown in Table 5.

Figure 5 Superimpose contour Graph with desirability

The Superimposed contours of all responses for blade angle and impact load (Fig. 6), for rotating speed. (Fig. 7) and their intersection zone for minimum actual force, maximum cutting efficiency and maximum collection efficiency indicated the ranges of variables which could be considered as the optimum range for best for crop residue mobile disintegrator machine. The ranges of optimum values of independent variables obtained from the superimposed contour are as

Cutting force; 9.2 N Cutting efficiency: 98.07 % collection efficiency;-81.11 %

Table 6 Solutions generated by the software for optimum conditions of responses mobile disintegrator machine

Solutions				
Number	blade angle	Impact Load	Speed	Actual force
1	105	20	1800	9.208

The above table 6 shows that the software generated optimum conditions of independent variables with the predicted values of responses. Solution number one, having the maximum desirability value (0.92) with minimum blade angle of 9.2kg/ha and 98.207% cutting efficiency and maximum collection efficiency was selected as the optimum conditions for mobile disintegrator Optimum value of independent variable is obtained by numerical optimization

Blade Angel:-105⁰ Impact Load;-20N cutting speed:- 1800rpm

Figure 6

Figure 7

6.4. Verification of the model for Mobile Disintegrator machine in CRS plot

The experiments of straw cutting mechanism were conducted at the optimum conditions and straw cutting performance of straw cutting blade were determined. The actual experimental values are given in Annexure A to C. The observed experimental values and predicted by the equations of the model are presented in Table 7. The predicted values were found to be within acceptable variations (0 to 7.01) with the experimental values of the variables of cutting force (N), cutting efficiency%, collection efficiency %.(indicated the suitability of the corresponding models.

Table 7 Comparison between predicated and actual response variables at optimum conditions for straw cutting mechanism

Sr No	Responses	Predicted value	Actual Value		Variation
1	Actual Force	9.20N	8.81	0.38	0.99
2	Cutting Efficiency	98.02%	96.17	1.34	1.88
3	Collection Efficiency	81.11	78.75	2.36	2.90

6.5. Conducting filed test in the cotton research station plot

The optimized mobile disintegrator machine with blade angel of 105⁰ was attaché to the shaft. The machine was operated with the help of tractor PTO at rated RPM to obtaining the optimize speed i.e 1800 rpm. The speed of tractor was keep in the range 2.50to 2.80Km/hr for the trials

After comparison with the predicted data with actual value the most of the observation variation is lies in 1 to 3 %

6.6. PFT (PROTOTYPE FIELD TESTING)

The average filed efficiency of the machine was observed in the range of 90.29 to 92.29% .The cutting efficiency of machine was observed as in the range of 97.18to 97.58 %Where as the average collection efficiency of the machine was observed in

the range 77.96 to 80.92%. The machine was satisfactory work with easy of operation. The average fuel consumption for the operation was 2.77 lit /hr. and the cost of operation was 917.52Rs/ ha. From the above it was concluded that the machine works satisfactorily with the 1050 blade angle and at 1800rpm to obtain the maximum cutting and collection efficiency

7. CONCLUSION

THE FOLLOWING CONCLUSIONS ARE MADE FROM THE PRESENT STUDY

The use of Design Expert 10.0.2 software for experimental design with the factorial Box-Behnken design matrices method was suitable for optimized solution of the blade angle. Which provides the optimized solution of the blade angle of 105° with an impact load of 20 N at a speed of 1800 rpm. This reduces the efforts required in vast testing procedures with utilizing the all type of blade on the large field.

The software generated optimum conditions of independent variables with the predicted values of responses. Solution number one, having the maximum desirability value (0.92) with minimum blade angle of 9.2kg/ha and 98.207% cutting efficiency and maximum collection efficiency was selected as the optimum conditions for mobile disintegrator

Contour and surface plots for cutting force, cutting efficiency and collection efficiency of mobile disintegrator machine show that the interactions of input parameters are prominent for both the responses. These plots may help to predict response (s) at some selected parametric combination(s).

The above optimum parametric combination has been validated by confirmatory tests.

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