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CONTENTS

Data prediction for calibration of seed drill using multiple linear regression

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ABSTRACT: Seed drill with fluted-roller seed metering devices is the mostly used for sowing of wheat crop in India. For obtaining the high yield, it is very essential to drop the wheat seeds in rows maintaining accurate seed rate with minimum damage to seeds during metering. This mainly depends on forward speed of the ground wheel, exposure length of the fluted-roller seed metering mechanism and hopper depth. The relationship between these factors and the dependent parameter, i.e., seed rate can be established using multiple linear regression analysis. Hence, an attempt has been made to develop the multiple linear regression (MLR) model using 3 Factor Completely Randomized Design for the prediction of the performance parameters (seed rate) of the fluted-roller seed metering device using speed of ground wheel, hopper depth and exposure length as input parameters. The data were generated in the laboratory by conducting experiments on a sticky belt test setup. The generated data was used to develop statistical model. All independent parameters such as hopper depth, exposure length and speed of ground wheel were found highly significant on seed rate. The R^2 values for MLR model during training, validation and testing were found to be 0.983, 0.988 and 0.986 respectively and RMSE values during training, validation and testing were found to be 17.84, 14.84 and 13.71 respectively

Key words*:* Fluted-roller seed metering mechanism, multiple linear regression (MLR) model, seed drill, wheat

In India, the share of the agricultural sector in GDP is less than 20%, while near about 70% of the population depends on agriculture for their livelihood. The essence of agriculture and the success of all subsequent operations in agriculture is determined by sowing. It becomes one of the most important operations in the cultivation of cereals and other crops.

Seed drills and planters with different types of metering mechanisms are introduced in India for the sowing and planting of different crop seeds. The fluted roller metering mechanism is widely used in seed cum fertilizer drills for metering seeds and fertilizers (Al-Mallahi and Kataoka, 2013). In a seed cum fertilizer drill, more than one seeds/fertilizer granules are dropped at a time in clumps due to the use of fluted rollers. Although the variation in the flow of seeds or fertilizer cannot be evaded due to the use of fluted rollers, it is a common practice to calibrate the drill before sowing (Zheng *et al.*, 2013; Fulton *et al.*, 2013).

A seed drill is expected to deliver a set quantity of seed at a given rate. Depending on the number of furrow openers, each opener delivers a specific amount of seed per given area. Sometimes the seeds delivered may be more or less than what the machine is set to deliver, and when this occurs, it calls for adjustment of the seed metering device and this is referred to as calibration (Mutai, 2015).

In statistics, linear regression is a linear approach to modeling the relationship between a scalar response and one or more explanatory variables (also known as dependent and independent variables). The case of one explanatory variable is called simple linear regression; for more than one, the process is called multiple linear regression. In linear regression, the relationships are modeled using linear predictor functions whose unknown model parameters are estimated from the data called as linear models.

Seed fertilizer drills with fluted-rollers generally utilize a calibrated relationship between the fluted-roller rotation speed and mass flow rate to control the application rate. However, this relationship model gradually deteriorates with operating time and is easily affected by working conditions. The calibration process can be carried out effectively by a skilled person as in the case of the laboratory calibration method.

A self-calibrating model can be designed, to maintain the initial operating accuracy. The parameters such as application rate, fluted-rollers rotation speed, the rotation speed of ground wheel, depth of seed and fertilizer in the hopper, no. and area of openings of notches in metering plate, width to be covered, forward speed of the tractor, etc. data during the operation process of fluted-roller metering mechanism can be used to dynamically establish the calibrated relationship. This model will provide all the required data for setting the seed drill in such a way that the seed rate throughout the sowing operation remains constant. The advantages of the self-calibrating model are that it will be economical, time-saving and will also contribute to precision farming.

The objectives of the study carried out were:

1. To collect the data for seed drill calibration using a sticky belt setup.
2. To study the relationship between a dependent (seed rate, kg/ha) and independent (exposure length, forward speed, depth of hopper, etc) variables.
3. To develop a linear regression model for calibration of seed drill.

MATERIALS AND METHODS

Experimental Setup

The indoor trials were performed using a sticky belt setup. A seed drill equipped with fluted-roller metering mechanism having 9 rows with row-row spacing of 225 mm was mounted over the sticky belt. The mounting of seed drill was employed using the mounting mechanism available in the laboratory. A 10 m long belt was allowed to travel at different settings of speed under the furrow openers or seed tubes in such a way that the speed of the belt is equal to the running speed of the drill. Standard calibration procedure was followed as per the test code IS:6316:1993 provided. The speed was varied with the help of the speed controlling unit. The speed was increased by 5 rpm each time starting from 30 rpm then next 35 rpm and so on. Polythene bags were placed under each boot for the collection of seeds. The ground wheel was given 10 revolutions for different speed settings and the amount of seeds falling from the metering device was collected in each bag and was weighed and readings were recorded in the datasheet. For each combination of independent variables, three observations were made to minimize the error of variation.

Table 1: Experimental Plan

RPM	Hopper Depth (mm)	Exposure Length (mm)
30, 35, 40, 45, 50	Half (120)	10, 20, 30, 40, 50
30, 35, 40, 45, 50	¾th full (180)	10, 20, 30, 40, 50
30, 35, 40, 45, 50	Full (240)	10, 20, 30, 40, 50

Data Collection

In this study, the speed of ground wheel, exposure length of fluted-roller seed metering mechanism and hopper depth were selected as independent parameters, and seed rate was considered as the dependent parameter.

Table 2: Details of independent and dependent variables

Independent Variables	Unit
Speed of ground wheel	kmh^{-1}
Exposure Length	mm
Hopper Depth	mm
Dependent Variable	
Seed Rate	kgha^{-1}

In this study, Lok-1 variety of wheat seeds were used. The physical properties of wheat seeds are stated in the result and discussion (Table 3). The laboratory tests were carried out at five different speeds of ground wheel, five different exposure lengths and three different hopper depths of the fluted-roller seed metering device. The levels of these variables are given in Table 3.1. The motor was set to run at 30, 35, 40, 45 and 50 rpm resembling the speed of ground wheel at 2.77, 3.23, 3.69, 4.15 and 4.61 kmh^{-1}, respectively. Initially, the test was conducted by varying the speed of ground wheel while keeping other parameters constant. Similarly, other observations were taken by varying all independent parameters one by one while keeping the rest parameters constant. The bags were placed for collection of seeds after every 10 revolutions from all 9 rows. The test setup was run for ten revolutions corresponding to each set of independent parameters.

The quantity of metered seeds in 10 revolutions was collected in polythene bags. The seeds collected in each bag were weighed on an electronic weighing balance and the data was recorded in datasheet. Three replications were taken for each set of conditions, and the corresponding seed rate was computed. These data were further utilized to develop the MLR model using 3 factor FCRD for predicting the seed rate.

Multiple Linear Regression (MLR) Model

Multiple or multivariate linear regression is a case of linear regression with two or more independent variables. For the case of more than two independent variables similar to this research problem, the estimated regression function is

$$Y = a_0 + a_1 x_1 + ... + a_p x_p \quad .... (1)$$

Where, Y = Predicted or expected value of the dependent variable

x_1 to x_p = p distinct independent or predictor variables

a_0 = value of Y when all of the independent variables (x_1 through x_p) are equal to zero

a_1 to a_p = the estimated regression coefficients.

Each regression coefficient represents the change in Y relative to a one-unit change in the respective independent variable. In the multiple regression situation, a_1, for example, is the change in Y relative to a one-unit change in x_1, holding all other independent variables constant (i.e., when the remaining independent variables are held at the same value or are fixed). Again, statistical tests can be performed to assess whether each regression coefficient is significantly different from zero. The 3 factor FCRD was used as a statistical package to develop MLR model for seed rate as functions of hopper depth, exposure length, and speed of ground wheel.

Evaluation Metrics for Regression Analysis

To understand the performance of the regression model performing model evaluation is necessary. Some of the evaluation metrics used for regression analysis are:

1. R squared or Coefficient of Determination

The most commonly used metric for model evaluation in regression analysis is R squared. It can be defined as a ratio of variation to total variation. The value of R squared lies between 0 to 1, the value closer to 1 the better the model.

$$R^2 = 1 - \frac{SS_{RES}}{SS_{TOT}} \quad .... (2)$$

where, SS_{RES} = Residual Sum of squares and SS_{TOT} = Total Sum of squares

2. Adjusted R square

It is the improvement to R squared. The problem/drawback with R^2 is that as the features increase, the value of R^2 also increases which gives the illusion of a good model. So the Adjusted R^2 solves the drawback of R^2. It only considers the features which are important for the model and shows the real improvement of the model. Adjusted R^2 is always lower than R^2.

$$R^2 adjusted = 1 - \frac{(1-R^2)(N-1)}{N-p-1} \quad .... (3)$$

Where, R^2 = Sample R-square

p = No. of predicators

N = Total sample size

3. Mean Squared Error (MSE)

Another common metric for evaluation is Mean squared error which is the mean of the squared difference of actual vs predicted values.

$$MSE = \frac{1}{n}\sum (y_a - y_p)^2 \quad .... (4)$$

$(y_a - y_p)^2$ = Square of difference between actual and predicted values.

4. Root Mean Squared Error (RMSE)

It is the root of MSE i.e., the root of the mean difference of actual and predicted values. RMSE penalizes the large errors whereas MSE doesn't.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} (y_{ai} - y_{pi})^2} \quad .... (5)$$

Where, n = sample size,

$y_{ai} - y_{pi}$ = difference between actual and predicted value.

RESULTS AND DISCUSSION

Effect of Various Independent Parameters on Seed Rate

Seed rate is the quantity of seed that is required to sow a unit area of land for optimum crop production. For the study purpose, three levels of hopper depth (with dimensions of hopper as l x b x h = 120 cm x 20 cm x 24 cm) were considered as 0.5 level (1/2 level), 0.75 level (3/4th full) and 1 level (full), five levels of ground wheel speed i.e., 2.77 kmh^{-1}, 3.23 kmh^{-1}, 3.69 kmh^{-1}, 4.15 kmh^{-1} and 4.61 kmh^{-1} along with five levels of exposure length of fluted roller i.e., 10 mm, 20 mm, 30 mm, 40 mm and 50 mm were considered. The data was recorded at all levels of hopper depth, speed of ground wheel and exposure length by varying one parameter at a time. Statistical analysis was performed using 3 factor FCRD package to study the effect of hopper depth, speed of ground wheel and exposure length on seed rate. Table 4 shows the results of the Univariate Analysis of Variances that all independent parameters such as hopper depth, exposure length and speed of ground wheel were found highly significant on seed rate. The combine effect of hopper depth (D) and exposure length (L) was found significant on seed rate at 99 per cent confidence level. The combine effect of various combinations like speed of ground wheel (S) and hopper depth (D), speed of ground wheel (S) and exposure length (L) and three variable effect of speed of ground wheel (S) with hopper depth (D) and with exposure length (L) was found non-significant on seed rate.

The effect of variation of hopper depth, speed of ground wheel and exposure length on seed rate is discussed in the following paragraphs.

1. Effect of hopper depth on seed rate

The values of seed rate for three different level of hopper depth were compared along with different combinations of other independent parameters such as exposure length and speed of ground wheel and plotted through fig. 1(a) to 1(e). Trends of curves (fig. 1(a) to 1(e)) show that the seed rate increased linearly with increasing the hopper depth. The highest seed rate was found when the hopper was

Table 4: ANOVA showing effect of hopper depth, speed of ground wheel and exposure length and their interaction on seed rate

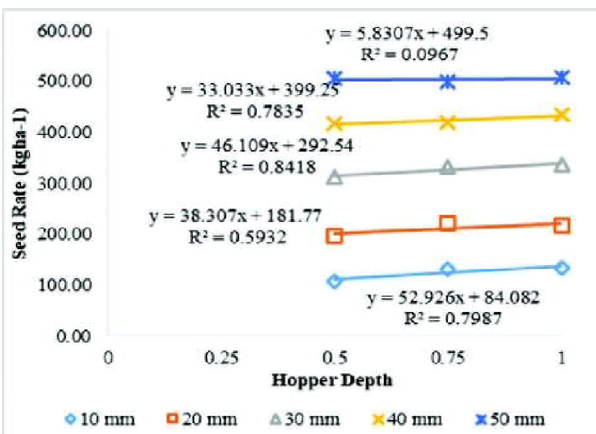
SOURCE of Variance	Degree of Freedom	Sum of Squares	Mean Sum of Squares	Computed-F	TAB F 5%	TAB F 1%	CV%
Speed of Ground Wheel (S)	4	2300.66	575.17	8.74**	2.43	3.45	
Hopper Depth (D)	2	16974.22	8487.11	128.94**	3.06	4.75	
Exposure Length (L)	4	4396608.08	1099154.15	16698.77**	2.43	3.45	2.52
S X D	8	197.17	24.65	0.37ns	2.00	2.63	
S X L	16	866.59	54.16	0.82ns	1.71	2.12	
D X L	8	3645.56	455.69	6.92**	2.00	2.63	
S X D X L	32	678.71	21.21	0.32ns	1.52	1.80	
ERROR	150	9873.35	65.82				
TOTAL	224	4431144.34					

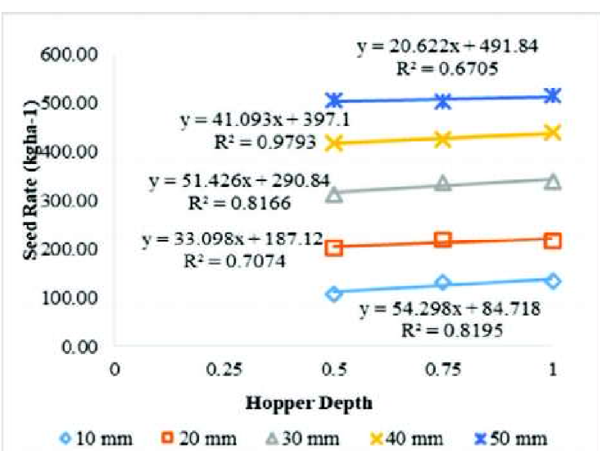
** Significant at 1% level, ns non-significant full with an exposure length of 50 mm. Thus, already established relationship between hopper depth, exposure length and seed rate was justified again. The system could not be operated satisfactorily at 50 mm exposure length with lowest ground wheel speed of 2.77 kmh^{-1} as shown in fig. 1(a) as the seed drill is generally not operated in field at such lowest speed as well as at highest exposure length. fig. 1(e) show that the highest seed rate was found to be 527.46 kgha^{-1} at full hopper depth with 50 mm exposure length for ground wheel speed of 4.61 kmh^{-1}.

Table 5: Mean values of seed rate at different hopper depth

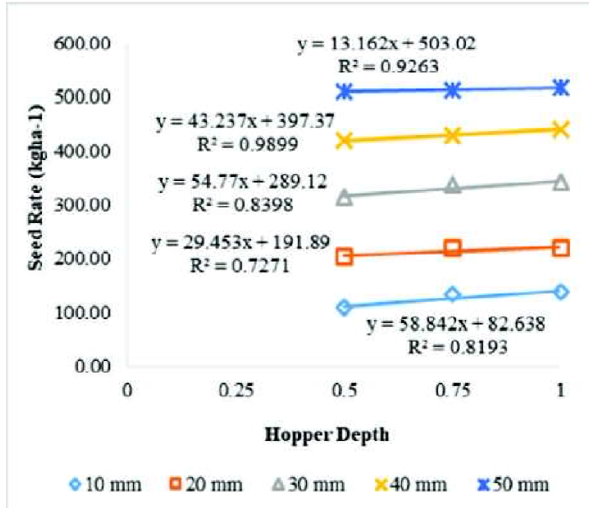
Hopper Depth	0.5	0.75	1
Mean Seed Rate, kgha^{-1}	311.45	318.88	323.33

SEm 0.94 CD 2.62

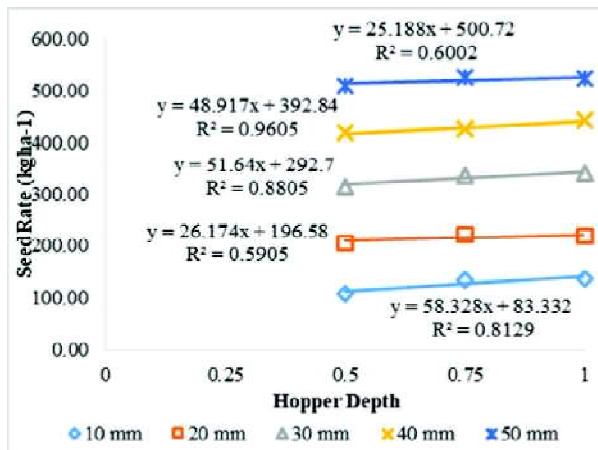




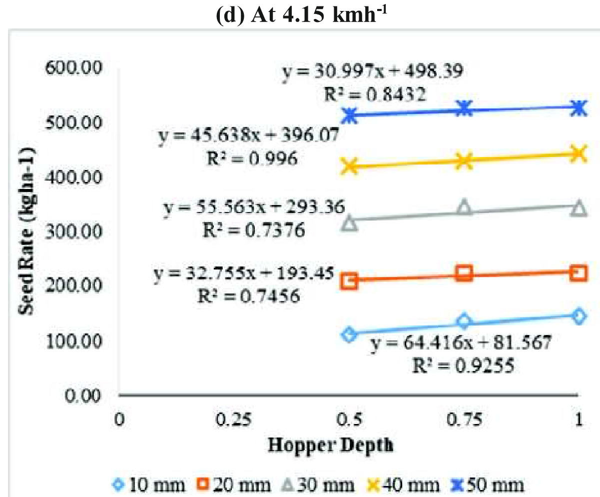
(b) At 3.23 kmh^{-1}



(c) At 3.69 kmh^{-1}



(d) At 4.15 kmh^{-1}



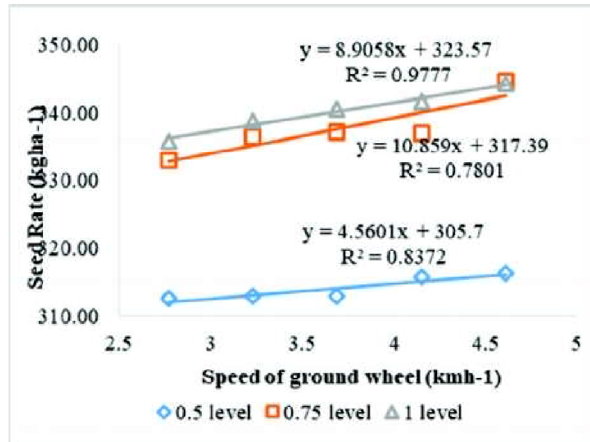
(e) At 4.61 kmh^{-1}

Fig. 1: Effect of hopper depth on seed rate at different exposure length with different speeds of ground wheel., (a) 2.77 kmh^{-1} (b) 3.23 kmh^{-1} (c) 3.69 kmh^{-1} (d) 4.15 kmh^{-1} (e) 4.61 kmh^{-1}

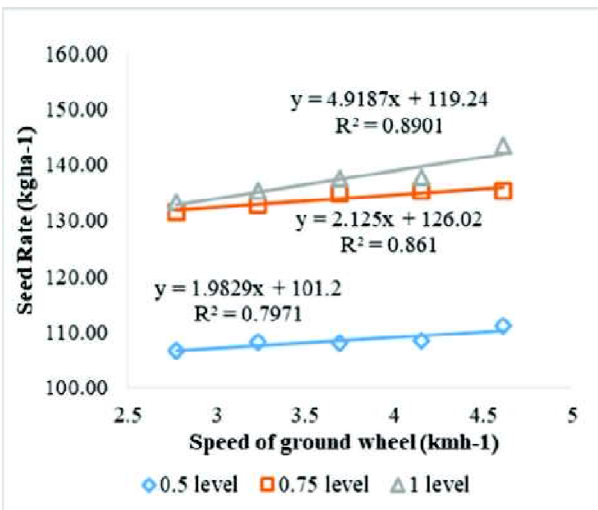
The following graphs shows the variation of hopper depth on seed rate at different exposure length for all speeds of ground wheel.

2. Effect of speed of ground wheel on seed rate

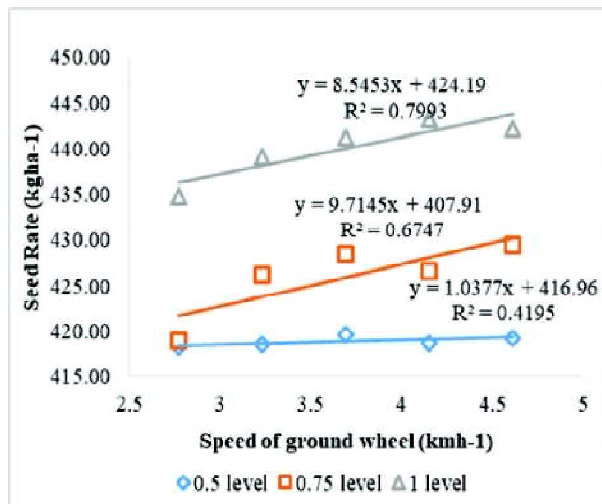
The values of seed rate for five different levels of speed of ground wheel were compared along with different combinations of other independent parameters such as hopper depth and exposure length and are plotted through fig. 2(a) to 2(e). Trends of curves (fig. 2(a) to 2(e)) shows that the seed rate



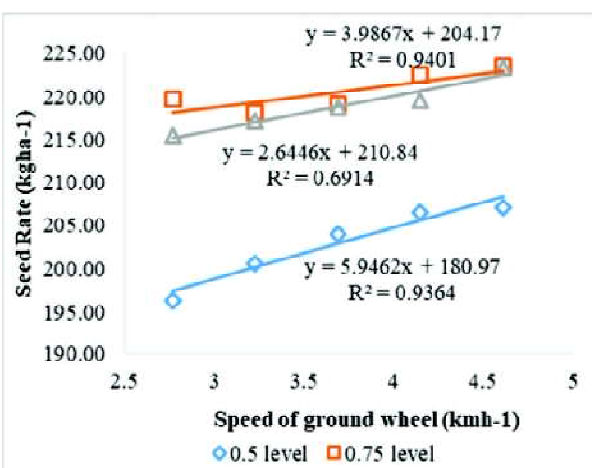
(c) At 30 mm



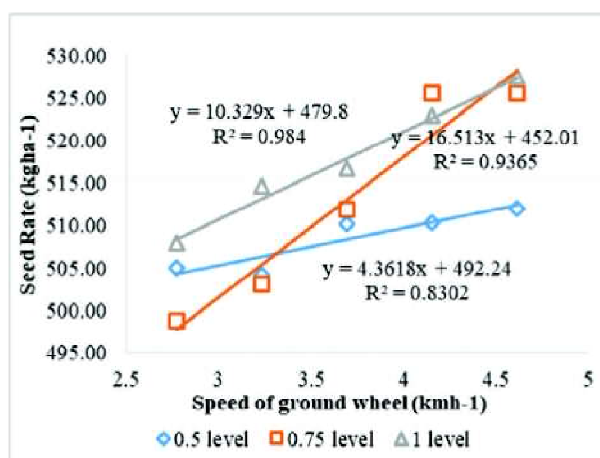
(a) At 10 mm



(d) At 40 mm



(b) At 20 mm



(e) At 50 mm

Fig. 2: Effect of speed of ground wheel on seed rate at different hopper depth with different exposure lengths. (a) 10 mm (b) 20 mm (c) 30 mm (d) 40 mm (e) 50 mm

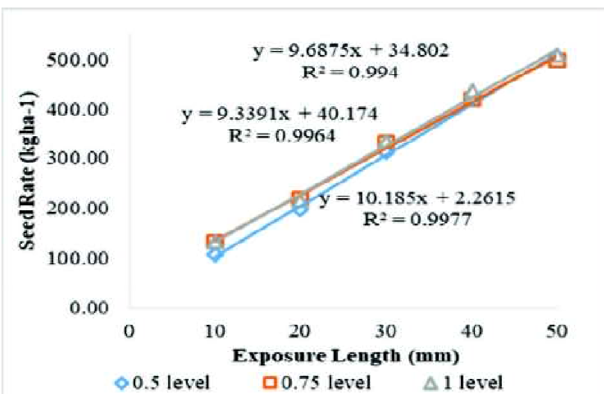
increased linearly with increasing the speed of ground wheel. The highest seed rate was found at the ground wheel speed of 4.61 kmh^{-1} with full (1 level) seed in hopper.

Table 6: Mean values of seed rate at different speed of ground wheel

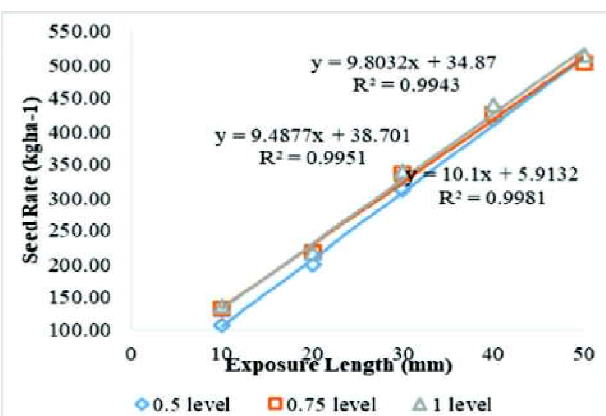
Speed of ground wheel, kmh^{-1}	Mean Seed Rate, kgha^{-1}
2.77	317.46
3.23	317.50
3.69	318.20
4.15	318.38
4.61	318.39

SEm 1.21 CD 3.38

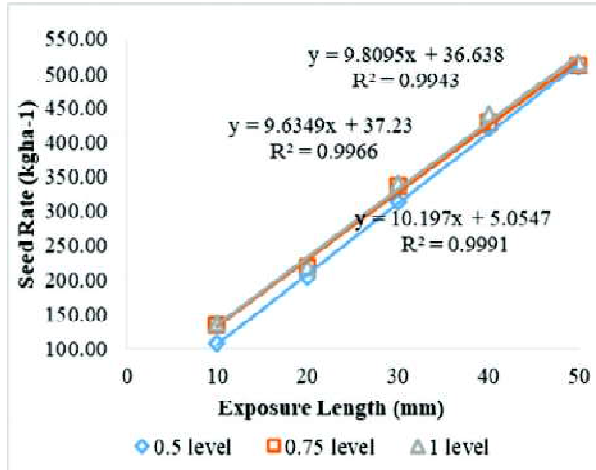
The following graphs shows the variation of speeds of ground wheel on seed rate at different hopper depth for all exposure lengths.



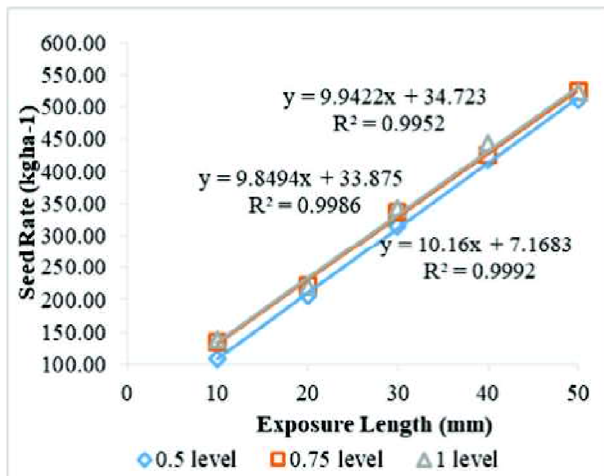
(a) At 2.77 kmh^{-1}



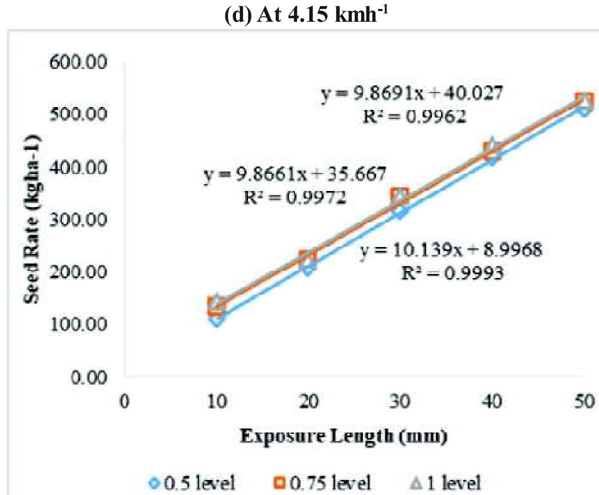
(b) At 3.23 kmh^{-1}



(c) At 3.69 kmh^{-1}



(d) At 4.15 kmh^{-1}



(e) At 4.61 kmh^{-1}

Fig. 3: Effect of Exposure Length on Seed Rate at different Hopper Depth with different Speeds of Ground Wheel. (a) 2.77 kmh^{-1} (b) 3.23 kmh^{-1} (c) 3.69 kmh^{-1} , (d) 4.15 kmh^{-1} (e) 4.61 kmh^{-1}

3. Effect of exposure length on seed rate

The values of seed rate for five different levels of exposure length were compared along with different combinations of other independent parameters such as hopper depth and speed of ground wheel and are plotted through fig. 3(a) to 3(e). Trends of curves (fig 3(a) to 3(e)) show that the seed rate increased linearly with increasing the exposure length. The highest seed rate was found at an exposure length of 50 mm with full (1 level) seed in hopper.

Table 7: Mean values of seed rate at different exposure length

Exposure Length, mm	Mean Seed Rate, $kgha^{-1}$
10	124.18
20	209.50
30	323.46
40	432.79
50	500.12

SEm 1.21 CD 3.38

The following graphs show the variation of exposure length on seed rate at different hopper depth for all speeds of ground wheel.

4. Combine effect on change in seed rate at different hopper depth and exposure length

Apart from effect of individual parameters on change in seed rate discussed earlier Table 4 (ANOVA) shows the combined effect of hopper depth, speed of ground wheel and exposure length and their interaction on the change in seed rate. It shows that the combined effect of hopper depth with exposure length is highly significant. It helps us in determining the optimum adjustment parameters to a great extent. The mean values of the seed rate for significant terms are shown in Table 8. The table shown below gives the model predicted optimum operating parameters for seed drill calibration.

The two variable interaction between hopper depth and exposure length on seed rate is shown in Table 8 which was found highly significant. It shows that

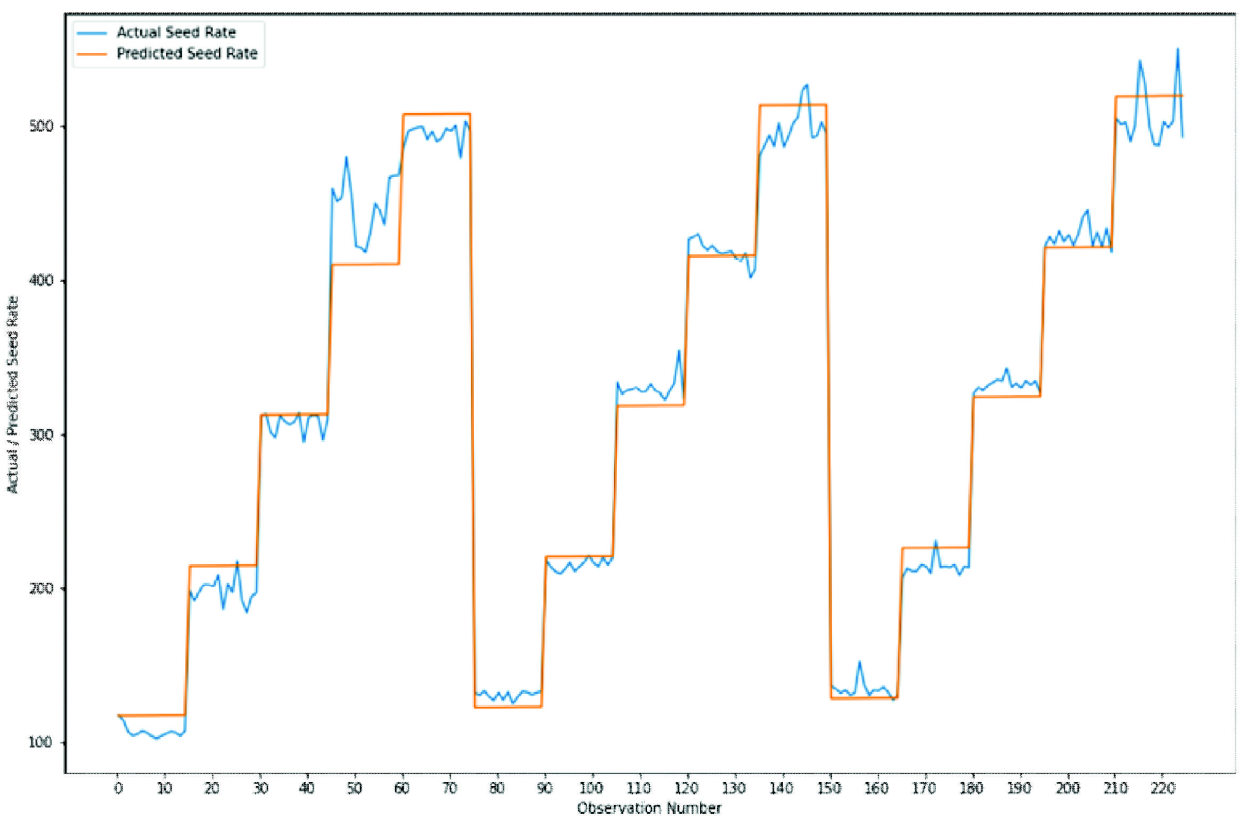


Fig. 4: Comparison of experimental values and MLR predicted values of seed rate

Table 8: Two Variable interaction showing effect of hopper depth with exposure length on mean seed rate

Hopper Depth	Mean Seed Rate, $kgha^{-1}$				
	Exposure Length, mm				
	10	20	30	40	50
0.5 (Half)	106.95	198.59	307.42	448.87	495.38
0.75 (3/4th Full)	131.21	215.74	330.16	418.87	498.46
1 (Full)	134.37	214.06	332.79	428.94	506.51

SEm 2.09 CD 5.85

the optimum parameters for effective working of seed drill was found at an exposure length of 10 mm and half (0.5) hopper depth having seed rate 108.64 $kgha^{-1}$. Generally, the range of seed rate for wheat varies from 100-120 $kgha^{-1}$. So, as compared to this seed rate, there is a saving of about 11.36 $kgha^{-1}$ of seed if the seed drill is operated at a setting of 10 mm exposure length and half hopper depth.

This model aids in understanding how seed rate changes with speed of ground wheel, exposure length and hopper depth and what values of these variables are required to achieve the optimal value of seed rate.

Performance evaluation of developed MLR model

The MLR models are known as robust modelling approaches, especially when there are linear relationships between the input and output variables. To determine the strength of the linear regression in predicting the seed rate the inputs and output data which were previously recorded were used for the MLR model, and the following equation was computed to predict the seed rate:

Seed rate = 5.86 + 0.85*speed + 9.74*exposure length + 23.91*hopper depth …. (6)

According to Eq. 6, the predicted value of seed rate was a linear transformation of speed of ground wheel, exposure length and hopper depth, such that the deviations of the observed and predicted seed rate was minimum. Therefore, a linear relationship between seed rate and other independent variables in the model can predict seed rate with good accuracy. Statistical analysis was performed to study the effect of independent parameters (hopper depth, speed of ground wheel and exposure length) on dependent parameter (seed rate). Table 9 shows the results of the Univariate Analysis of Variances.

Table 9: ANOVA showing results of multiple linear regression analysis

Source	Regression	Error	Total
df	3	221	224
SS	4281379.4	63687.972	4345067.3
MS	1427126.5	288.18087	
F	4952.19		
Significance F	2.6E-202		

To validate the above developed MLR model a data set was used to compare the actual and the model predicted value. The comparison of actual and MLR model predicted values are shown further with the help of a graph in fig.4.

To understand the performance of the regression model some of the evaluation metrics are used for regression analysis. Table 10 shows the evaluation metrics for multiple regression analysis.

Table 10: Evaluation metrics for multiple linear regression analysis

Regression Statistics	
Multiple R	0.992644
R Square	0.985342
Adjusted R Square	0.985143
Standard Error	16.97589
Observations	225

Fig.4 shows the comparison of actual and the model predicted seed rates for all the observations. From the graph, it can be depicted that blue line shows the actual seed rate values that were calculated from laboratory experiments and orange line shows the seed rate values that MLR model predicted when we input the same parameters as those used for laboratory calibration of seed drill. The graph shows that both the actual and model predicted values are close enough which means that the MLR model developed, performed well for calibrating the seed drill at given input parameters. Thus this model can be used for finding the appropriate seed rates at different adjustments for seed drills.

CONCLUSION

Statistical analysis was performed using 3 factor FCRD package to study the effect of hopper depth, speed of ground wheel and exposure length on seed rate. The following conclusions were drawn from the study.

1. All independent parameters such as hopper depth, exposure length and speed of ground wheel were found highly significant on seed rate.
2. The combine effect of hopper depth (D) and exposure length (L) was found significant on seed rate at 99 per cent confidence level whereas the combine effect of various combinations like speed of ground wheel (S) and hopper depth (D), speed of ground wheel (S) and exposure length (L) and three variable effect of speed of ground wheel (S) with hopper depth (D) and with exposure length (L) was found non-significant on seed rate.
3. The R^2 values for MLR model during training, validation and testing were found to be 0.983, 0.988 and 0.986 respectively.
4. The RMSE values for MLR model during training, validation and testing were found to be 17.84, 14.84 and 13.71 respectively.
5. Performance prediction of MLR model for fluted-roller having RMSE value 16.84 for complete dataset was good with R^2 value 0.985.
6. R^2 value close to 1 and lower RMSE value depicts that the developed model performed well for the given inputs.
7. The model can be trained and modified for other crops as well as other metering mechanism.
8. Model can also be optimized further by including more independent parameters and by developing a proper User Interface it can be made more useful for future prediction work.

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