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Optimization of the Distribution Uniformity of a Single-Disc Granular Broadcast Spreader

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Abstract: The objective of this study was to optimize the distribution uniformity performance of a single-disc granular broadcast spreader. The performance indicators were considered to be the coefficient of variation (CV, %) and skewing ratio (left to right or right to left ratio of the granular material applied). Central Composite Design (CCD) which is rotatable and one of the designs in Response Surface Methodology (RSM) was used in order to optimize the distribution uniformity. Two different fertilizers (urea and triple super phosphate) were used and a total of 20 experiments for each fertilizer were conducted. Each experiment was triplicated. The independent variables considered in this study were the peripheral speed of the disc (corresponding to power take-off linearly), the fertilizer flow rate and the impeller angle. The dependent variables were the coefficient of variation (CV, %) and skewing ratio (either right to left or left to right distribution). Mathematical functions in polynomial form were developed based on the principles of RSM that allowed conducting reduced number of experiments as compared to full factorial design. The optimum levels of the variables were obtained and verification tests were also achieved. It was concluded that the three variables considered in this study affect the distribution uniformity performance of the broadcast spreader.
Key words: Mathematical modeling, response surface methodology, skewing, fertilizer, granular material

INTRODUCTION

Rotary spreaders are very simple in terms of construction but their performance is such a phenomena that numerous studies have been conducted in the past to find out the best spreading pattern since many operational, constructional and material related variables affect the performance. The performance of a broadcast spreader in order to provide even fertilizer distribution is characterized by the coefficient of variation (CV, %, standard deviation divided by average). The lower the CV (%) the more uniform the distribution is and this is why a minimum CV (%) is desired. The issue behind even fertilizer distribution is the net profit that can be obtained by a farmer at a maximized level. The CV (%) related to the systematical transverse spreading distribution is typically from 5 to 10% for the best spreaders and the CV below 15%, which is presumably is a realistic level for a good fertilizer spreaders, the relative loss of net profit, typically being close to 1%, is very moderate (Søgaard and Kierkegaard, 1994). The physical and chemical properties of the fertilizer being used, constructional variables such as the shape, height and the position of the impellers (Yıldırım and Kara, 2003; Güler, 1995), drop point of the fertilizer onto disc, etc.; Mennel ve Reece, 1963;) and operational related variables such as disc speed and the flow rate (Parish, 2002 and Yıldırım, 2006) affect the distribution pattern (skewing) and distribution uniformity as it was the case in many studies available in the literature. In general, the dimensions of the disc and the size, shape and the number of impellers, the drop point of fertilizer vary from one company to another and each construction becomes a case study to find out the best performance. Hence, the objective of this study was to optimize the distribution uniformity performance of a single-disc broadcast spreader manufactured by a local company.

* This is a part of the MSc thesis prepared by İsmail Serkan KOLCU (2012)

MATERIALS and METHODS

The broadcast spreader used for this study consists of a hopper, single-disc in the diameter of 480 mm, six [type impellers, gearbox and a simple frame and is driven by the power take-off. Spread pattern tests were carried out in outdoor areas on smooth, level pavement under conditions of no wind. Prior to the tests, the flow rate of the fertilizer was adjusted by changing the area of the two orifices located on the bottom of the hopper at corresponding peripheral speed of the disc (as linearly related to power take-off of the tractor). The collection trays were 472 mm long, 312 mm wide, and 110 mm high and the trays were subdivided to reduce granule bounce. Fertilizer particles collected in each tray was weighed using a precision balance with an accuracy of ± 0.01 g.

Each test consisted of three replications and in order to do this, three sets of collection trays were placed in a line perpendicular to the direction of travel of the spreader while enough space was left for the tractor tire pass. The distance between each set was 1.5 m. The tests were conducted at a constant forward speed of 8 km h^{-1}. Two granular fertilizers (urea and triple superphosphate) were applied during the tests. The bulk densities of these materials were 785 and 1025 kg m^{-3}, respectively. The pattern analysis in order to determine the overlapped patterns to find out CV (%) and skewing ratio was achieved in Excel and the coefficient of variation (CV, as defined by ASAE S341.3, 2004) along with skewing ratio was found. The Skewing ratio in this study was calculated either the ratio of right to left or the left to right in, whichever is lower than the unity since in ideal case the amount or the percentage of fertilizers distributed to the right or the left side of the spreader must be equal and in this case, the ratio of them will be unity. This type of calculation for the skewing ratio was also necessary in order to develop mathematical functions so that the upper limit of such a function can only be equal to unity.

As a statistical and mathematical technique, RSM was employed in order to optimize the operating (peripheral speed of the disc and flow rate) and constructional related variables (impeller angle). RSM designs are not primarily used for understanding the mechanism of the underlying system and assessing treatment main effects and interactions, but to determine, within some limits, the optimum operating conditions of a system (Myers, 1971). It is less laborious and time-consuming than other approaches and effective technique for optimizing complex processes since it reduces the number of experimental trials to evaluate multiple parameters and their interactions. The response surface problem usually centers on an interest in some response Y, which is a function of k independent variables ξ_i, ξ_j, ...,ξ_k , that is,

$$Y = f\,(\xi_i, \xi_j, ...,\xi_k) \qquad (1)$$

and response surface can take the different forms according to the function types of response and usually response function is defined in the quadratic polynomial form as follows.

$$Y=\beta_0+\sum_{t=1}^{k}\beta_i X_i+\sum\beta_{Ii}X_i^2+\sum_i\sum_j\beta_{ij}X_iX_j+\varepsilon,\ i\leq j \qquad (2)$$

where;

Y : Response (Dependent variable)

β_0 : Intercept

β_i, β_{ii}, β_{ij} : Regression coefficients

X_i X_j : Coded independent variables

E : Error

The coding of independent variables into X_i is expressed as in the following equation;

$$X_i=\frac{\xi_i-\xi^*}{d_s} \qquad (3)$$

where ξ_I;actual value in original units; ξ^*; mean value (center point) and d_s; step value.

For a better understanding and detailed theoretical knowledge on RSM, the reader is referred to read the textbook written by Box and Draper (1987). The design used in this study is a rotatable CCD and it requires five levels for each independent variable. These levels are coded as −1.682, −1, 0, +1 and +1.682. The coded and uncoded levels of the independent variables are given in Table 1.

Table 1. Coded and uncoded values of the independent variables used in CCD

Independent variable	Step value	Coded level				
		-1.682	-1	0	+1	+1.682
Disc peripheral speed (ω; ms^{-1})	3.2	11.82	14.01	17.21[ψ]	20.41	22.59
Flow rate (Q; kg min^{-1})	15	17	28	43	58	68
Impeller angle[ξ] (α; degrees)	12	-20	-12	0	+12	+20

[ξ]Minus and plus signs in angles indicate rearward and forward pitched impellers, respectively, [ψ]peripheral speed at 540 min^{-1} power take-off

Based on the above written theoretical approach in RSM, the variables were transformed to uncoded form (dimensionless) using the following equations.

$$X_1 = \frac{\omega - 17.21}{3.2} \quad (4)$$

$$X_2 = \frac{Q - 43}{15} \quad (5)$$

$$X_3 = \frac{\alpha - 0^o}{12^o} \quad (6)$$

Peripheral disc speed (ω in equation 4) is a function of pto linearly and disc speed of 17.21 ms^{-1} corresponds to pto of the tractor at 540 rpm. This speed was selected to be the center in order to achieve experiments based on CCD.

Flow rates considering the granular fertilizer application rates at 8 km h^{-1} forward speed of the tractor were selected within a range of 16 and 69 kg min^{-1} while the center was selected to be 43 kg min^{-1}. The center of the impeller was set to radial position (0^o) and rear and bacward positions was set to -12, -20, +12 and +20^o with a step value of 12^o.

RESULTS and DISCUSSION

The results from the experiments are tabulated in Table 2. The data from 20 experiments with three replications, totally 60 data points were used to develop functions for CV (Y_{cv}; %) and skewing ratio (Y_r) in polynomial form for both, urea and triple superphosphate (TSP). Arcsin$\sqrt{Y_r}$ transformation was applied to skewing ratio values and this transformation prevented the predicted skewing ratio values from being greater than unity. A general theoretical cubic function for four variables in full was defined and submitted to a statistical package program and stepwise regression procedure was applied in order to select the variables at a probability level of 95 %. The functions developed are given below for each fertilizer and variables, X_1, X_2 and X_3, are the disc peripheral speed, flow rate and impeller angle, respectively in coded form.

Urea functions

$$Y_{CV}=11.23+9.63X_3^2-4.68X_1X_2X_3+4.07X_1^2X_3+4.27X_2X_3+2.54X_1^2+2.26X_2^2-2X_1X_2+0.59X_3^3+2.19X_1X_2^2-0.8X_1^3 \quad R^2= 94.4\ (\%) \quad (7)$$

$$\text{Arcsin}\sqrt{Yr}=1.28-0.193X_3^2+0.129X_1X_2X_3-0.137X_3-0.046X_2^2-0.059X_2X_3-0.042X_2-0.041X_1X_3+0.031X_3^3-0.036X_1X_2^2 \quad R^2= 88.9\ (\%) \quad (8)$$

TSP functions

$$Y_{CV}=20.94+8.62X_1^2X_3+5.37X_3^2+3.91X_1^2-3.91X_1+2.46X_1X_2-2.25X_1X_3+2.25X_2X_3-0.66X_2^3 \quad R^2= 93.9\ (\%) \quad (9)$$

$$\text{Arcsin}\sqrt{Yr}=1.0722-0.1227X_1^2X_3-0.0787X_3^2+0.0498X_1+0.0553X_1X_3-0.0303X_1^2-0.0213X_2^2 \quad R^2= 88.6\ (\%) \quad (10)$$

The models given above are written in the order that the variables entered into the model so that the significance of each term to the model could be identified from this order and they are valid under the following conditions (in uncoded levels);

$$11.82 \geq \omega \geq 22.59$$
$$17 \geq Q \geq 69$$
$$-20 \geq \alpha \geq +20$$

where; ω = disc peripheral speed in ms^{-1}, Q; flow rate in kg min^{-1} and α; impeller angle in degrees.

Table 2. Performance values as obtained from the tests conducted based on CCD

Run number	Independent variables			Dependent (Performance) variables					
	Disc peripheral speed (X_1)	Flow rate (X_2)	Impeller angle (X_3)	Non-overlapped CV (%)		Lowest overlapped CV (%)		Skewing ratio (either left to right or right to left ratio)	
				Urea	TSP	Urea	TSP	Urea	TSP
1	-1 [14.01 ms^{-1}]	-1 [28 $kgmin^{-1}$]	-1 [-12^0]	46.11 (4.52)	29.66 (1.78)	25.72 (1.89)	24.12 (2.92)	0,67 (0.02)	0.76 (0.04)
2	1 [20.41 ms^{-1}]	-1 [28 $kgmin^{-1}$]	-1 [-12^0]	43.86 (3.47)	32.12 (2.78)	12.63 (0.59)	18.50 (2.35)	0,93 (0.05)	0.78 (0.04)
3	-1 [14.01 ms^{-1}]	1 [58 $kgmin^{-1}$]	-1 [-12^0]	52.03 (0.56)	26.12 (3.39)	21.18 (3.05)	24.06 (3.70)	0,91 (0.05)	0.73 (0.57)
4	1 [20.41 ms^{-1}]	1 [58 $kgmin^{-1}$]	-1 [-12^0]	41.21 (2.87)	22.63 (2.84)	19.49 (2.66)	21.80 (2.73)	0,70 (0.03)	0.75 (0.03)
5	-1 [14.01 ms^{-1}]	-1 [28 $kgmin^{-1}$]	1 [$+12^0$]	38.08 (6.01)	54.65 (2.95)	15.04 (2.11)	46.65 (3.15)	0,87 (0.06)	0.42 (0.02)
6	1 [20.41 ms^{-1}]	-1 [28 $kgmin^{-1}$]	1 [$+12^0$]	48.89 (5.18)	53.30 (1.67)	40.11 (3.91)	39.86 (3.96)	0,47 (0.03)	0.457 (0.02)
7	-1 [14.01 ms^{-1}]	1 [58 $kgmin^{-1}$]	1 [$+12^0$]	38.65 (1.62)	58.61 (7.61)	36.16 (4.90)	31.44 (3.06)	0,50 (0.04)	0.63 (0.03)
8	1 [20.41 ms^{-1}]	1 [58 $kgmin^{-1}$]	1 [$+12^0$]	39.85 (2.68)	68.32 (5.09)	31.50 (3.64)	36.85 (1.23)	0,53 (0.42)	0.634 (0.03)
9	-1.682 [11.82 ms^{-1}]	0 [43 $kgmin^{-1}$]	0 [0^0]	35.25 (3.89)	46.56 (2.67)	23.05 (1.42)	38.21 (0.95)	0,91 (0.04)	0.61 (0.01)
10	1.682 [22.59 ms^{-1}]	0 [43 $kgmin^{-1}$]	0 [0^0]	48.05 (6.86)	43.35 (5.65)	15.87 (1.67)	24.43 (2.42)	0,982 (0.55)	0.78 (0.04)
11	0 [17.21 ms^{-1}]	-1.682 [17 $kgmin^{-1}$]	0 [0^0]	33.34 (5.92)	36.33 (2.81)	18.90 (1.57)	25.84 (3.03)	0,86 (0.06)	0.69 (0.01)
12	0 [17.21 ms^{-1}]	1.682 [68 $kgmin^{-1}$]	0 [0^0]	33.45 (3.29)	36.42 (1.75)	20.02 (1.12)	18.80 (1.05)	0,80 (0.05)	0.75 (0.02)
13	0 [17.21 ms^{-1}]	0 [43 $kgmin^{-1}$]	-1.682 [-20^0]	65.37 (3.20)	62.02 (1.75)	36.29 (1.76)	35.47 (2.50)	0,59 (0.04)	0.58 (0.04)
14	0 [17.21 ms^{-1}]	0 [43 $kgmin^{-1}$]	1.682 [$+20^0$]	52.29 (3.13)	36.12 (1.23)	44.35 (3.07)	33.07 (1.30)	0,38 (0.03)	0.57 (0.02)
15	0 [17.21 ms^{-1}]	0 [43 $kgmin^{-1}$]	0 [0^0]	34.62 (3.40)	29.35 (4.40)	8.61 (0.47)	19.25 (1.01)	0,95 (0.02)	0.76 (0.31)
16	0 [17.21 ms^{-1}]	0 [43 $kgmin^{-1}$]	0 [0^0]	32.55 (1.08)	31.41 (1.64)	9.80 (0.21)	21.50 (1.44)	0,90 (0.01)	0.74 (0.007)
17	0 [17.21 ms^{-1}]	0 [43 $kgmin^{-1}$]	0 [0^0]	30.02 (1.08)	27.21 (3.03)	10.65 (0.04)	19.43 (3.20)	0,91 (0.02)	0.78 (0.38)
18	0 [17.21 ms^{-1}]	0 [43 $kgmin^{-1}$]	0 [0^0]	28.63 (1.54)	31.90 (3.18)	11.65 (0.63)	20.25 (1.96)	0,91 (0.04)	0.77 (0.07)
19	0 [17.21 ms^{-1}]	0 [43 $kgmin^{-1}$]	0 [0^0]	31.45 (2.13)	27.04 (2.78)	12.73 (0.07)	18.19 (2.26)	0,87 (0.02)	0.81 (0.04)
20	0 [17.21 ms^{-1}]	0 [43 $kgmin^{-1}$]	0 [0^0]	27.62 (0.38)	29.90 (2.20)	13.29 (0.35)	20.68 (2.25)	0,91 (0.46)	0.77 (0.03)

The numbers in brackets are the original level of the variables; the ones in parenthesis in the above table indicate the standard errors resulted from three replications. Non-overlapped CV (%) values are the ones the corresponds to the lowest overlapped CV values at the same swath width.

It is interesting that the first two terms entered into the model for each fertilizer are the same as seen above. For urea, the first two terms that entered into the model during stepwise regression analysis are X_3^2 (impeller angle) and $X_1X_2X_3$ (interaction of disc peripheral speed, flow rate and impeller angle). These terms make the highest contribution to explain the variation in CV (%) and skewing ratio. Just like urea, the TSP functions have the same structures since the first two terms, $X_1^2X_3$ (interaction of disc peripheral speed and impeller angle) and X_3^2 (impeller angle) are the same and they are the first two terms that entered into the models. It seems that the most significant variable seems to be the impeller angle as also found by Parish (2003); Yıldırım (2006). The other two variables also play a significant role in both, CV (%) and skewing ratio since they were included in the models either as a main variable or in an interaction form with other two variables. The effects of variables on CV (%) and skewing ratio are depicted in Figure 1 thru 12 for fertilizers used in this study. As seen from the surface graphs, there are certain levels of the variables that make the CV (%) values lowest while the skewing ratio reaches the highest level.

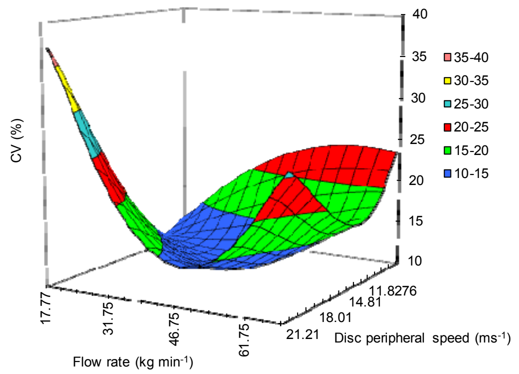

Figure 1. Variations in CV (%) as a function of flow rate and disc peripheral speed for urea (Impeller angle assumed at the center of CCD design, 0°)

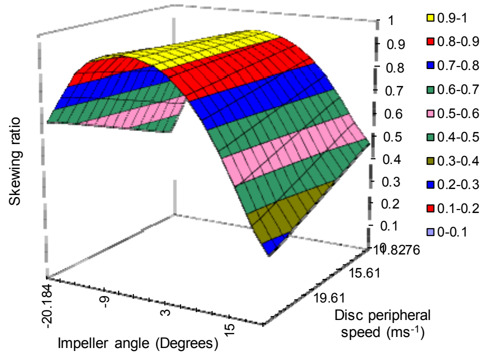

Figure 4. Variations in skewing ratio as a function impeller angle and disc peripheral speed for urea (flow rate assumed to be at the center, 43 kg min^{-1})

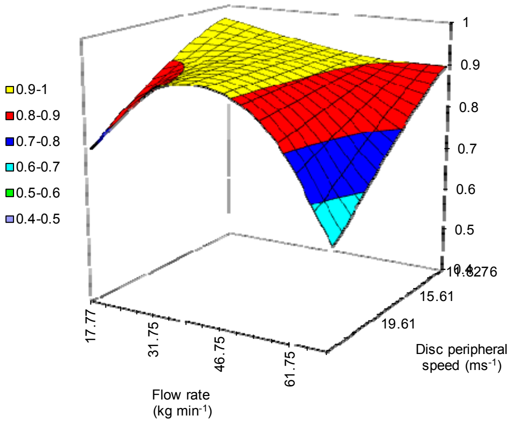

Figure 2. Variations in skewing ratio as a function of flow rate and disc peripheral speed for urea (Impeller angle assumed at the center of CCD design, 0°)

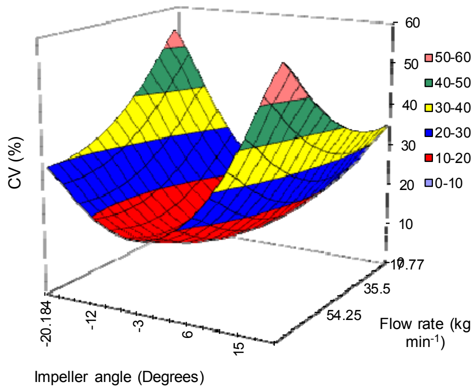

Figure 5. Variations in CV (%) as a function impeller angle and flow rate for urea (disc peripheral speed assumed to be at the center of CCD design, 17 ms^{-1})

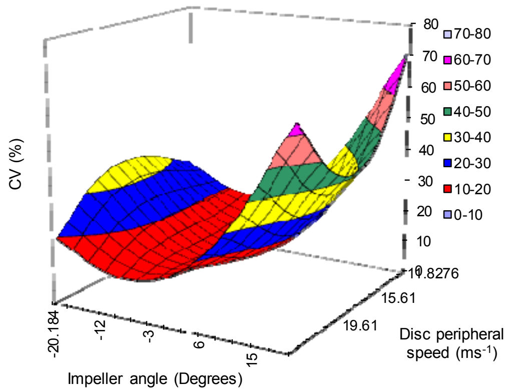

Figure 3. Variations in CV (%) as a function impeller angle and disc peripheral speed for urea (flow rate assumed to be at the center, 43 kg min^{-1})

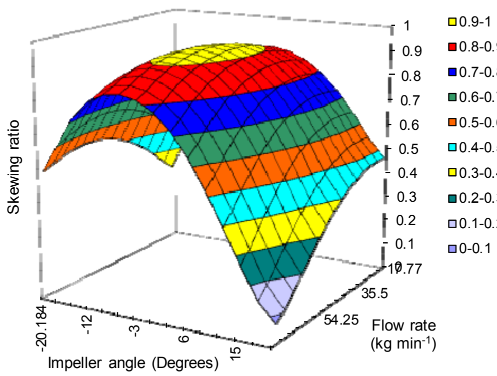

Figure 6. Variations in skewing ratio as a function impeller angle and flow rate for urea (disc peripheral speed assumed to be at the center of CCD design, 17 ms^{-1})

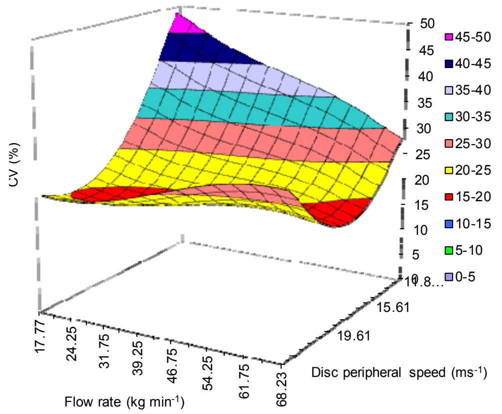

Figure 7. Variations in CV (%) as a function of flow rate and disc peripheral speed for TSP (Impeller angle assumed at the center of CCD design, 0°)

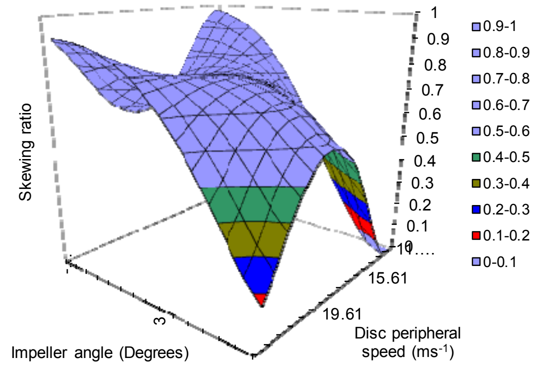

Figure 10. Variations in skewing ratio as a function impeller angle and disc peripheral speed for TSP (flow rate assumed to be at the center, 43 kg min^{-1})

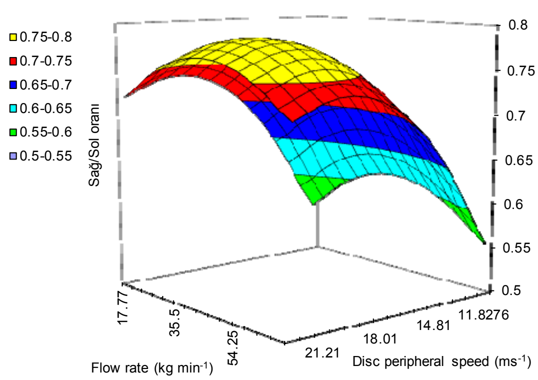

Figure 8. Variations in skewing ratio as a function of flow rate and disc peripheral speed for TSP (Impeller angle assumed at the center of CCD design, 0°)

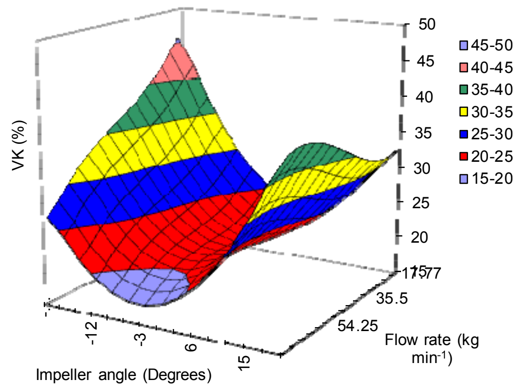

Figure 11. Variations in CV (%) as a function impeller angle and flow rate for TSP (disc peripheral speed assumed to be at the center of CCD design, 17 ms^{-1})

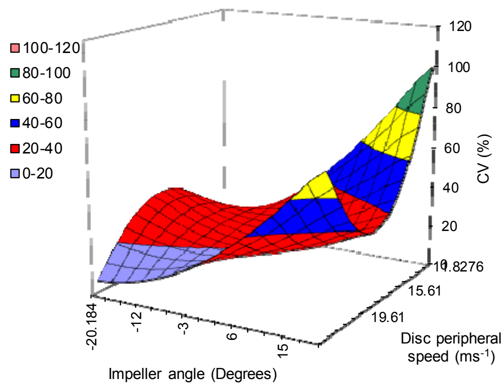

Figure 9. Variations in CV (%) as a function impeller angle and disc peripheral speed for TSP (flow rate assumed to be at the center, 43 kg min^{-1})

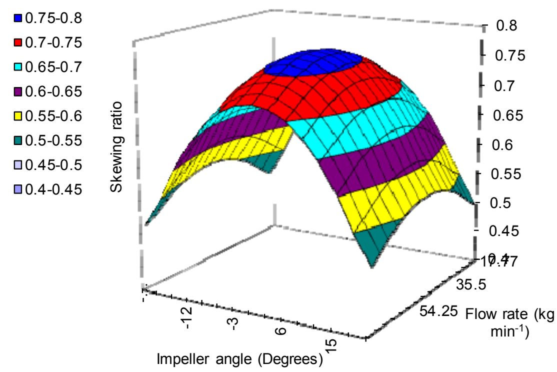

Figure 12. Variations in skewing ratio as a function impeller angle and flow rate for TSP (disc peripheral speed assumed to be at the center of CCD design, 17 ms^{-1})

From the polynomial functions given above, the optimum level of the variables was found using mathematical software called Maple and a special code was written in the program in order to make the necessary calculations. The results for each fertilizer are tabulated in Table 3 and 4. As seen from the tables, three are three sets of optimum values of the variables that make the CV (%) minimum while two sets of variables that make the skewing ratios maximum for urea as shown in Table 3. The CV values as calculated are within a narrow range between 11.23 and 12.44 %. The skewing ratio values calculated at the optimum level of the variables are 0.99. The CV polynomial functions for TSP resulted in two sets of optimum level of the variables that make the CV around 20%. The skewing ration model for TSP provided only one set of optimum level of the variables and the skewing ratio at these optimum points are around 0.9.

One of the steps in this type of RSM based optimization problems is to verify the optimum level of the variables and for this purpose some verification tests were achieved after calculating the optimum level of the variables and the findings from these tests are given in table 5 and 6 for urea and TSP, respectively. As seen from the tables, the optimum levels of the variables found from the CV (%) models are in good agreement as they were justified by the verification tests. It can be stated that disc peripheral speed ranging between 15 and 17 ms^{-1} (corresponds to 470 and 540 rpm of PTO) and the flow rate between 32 and 55 kg min^{-1} and the impeller angle of -4 and 0^{o} will provide the lowest CV (%) and maximized skewing ratio for urea. The values that make the CV values lowest but maximized for skewing ratio for TSP are ranging between 15 and 19 ms^{-1} (corresponds to (470 and 596 rpm of PTO) for the disc peripheral speed, 43 and 52 kg min^{-1} for the flow rate and -5 and -2^{o} for the impeller angle.

In practice, different fertilizer rates (kg ha^{-1}) can be required and this can be achieved by changing the forward speed of the tractor rather than 8 km h^{-1} if the optimum flow rates found in this study are used.

The CV (%) values obtained in this optimization based study can be considered to be the lowest CV values that can be obtained for this type of a spreader. But, it should be kept in mind that any changes in construction such as using different impellers in shape, height or length, changes in drop point of the fertilizer etc. may help reducing these CV values and this will require expanding the study in terms of independent variables to be considered and conducting a response surface based study such as this one.

Table 3. Optimum values of the variables obtained from the prediction functions for urea

Model	Variables (coded and uncoded values)			Predicted distribution uniformity values
	X_1	X_2	X_3	
CV % Model (Equation 4)	0.0223 [17.28 ms^{-1}] 0 [17.21 ms^{-1}] -0.396 [15.94 ms^{-1}]	0.803 [55 kg min^{-1}] 0 [43 kg min^{-1}] -0.684 [32.7 kg min^{-1}]	-0.0997 [-1.1^{o}] 0 [0^{o}] 0.181 [2.1^{o}]	12.44* 11.23* 11.46*
Skewing ratio model (Equation 5)	-0.7053 [14.95 ms^{-1}] -0.5663 [15.39 ms^{-1}]	0.263 [46.9 kg min^{-1}] -0.561 [34.5 kg min^{-1}]	-0.352 [-4.2^{o}] -0.1 [-1.2^{o}]	0.994** 0.993**

*Calculated CV (%) from the model at optimum levels; **Calculated skewing ratio from the model at optimum levels

Table 4. Optimum values of the variables obtained from the prediction functions for TSP

Model	Variables (coded and uncoded values)			Predicted distribution uniformity values
	X_1	X_2	X_3	
CV % Model (Equation 6)	0.581 [19.06 ms^{-1}] 0.451 [18.65 ms^{-1}]	0.633 [52.5 kg min^{-1}] 0.585 [51.7 kg min^{-1}]	-0.282 [-3.3^{o}] -0.191 [-2.2^{o}]	20.298* 20.292*
Skewing ratio model (Equation 7)	-0.555 [15.43 ms^{-1}]	0 [43 kg min^{-1}]	-0.435 [-5.2^{o}]	0.892**

*Calculated CV (%) from the model at optimum levels; ** Calculated skewing ratio from the model at optimum levels

Table 5. Verification test* results for urea

Model	Variables	Calculated performance values from the equations	CV values obtained from the verification tests (three replications)	Skewing ratio values obtained from the verification tests (three replications)
CV % Model (Equation 4)	X_1= 0.0223 [17.28 ms^{-1}] X_2= 0.803 [55 kg min^{-1}] X_3= -0.0997 [-1.1°]	CV=12.44 %	13.84 14.29 14.57	0.94 0.96 0.99
CV % Model (Equation 4)	X_1= 0 [17.21 ms^{-1} X_2= 0 [43 kg min^{-1}] X_3=0 [0°]	CV=11.23 %	12.73 13.25 13.54	0.9 0.91 0.99
CV % Model (Equation 4)	X_1=-0.396 [15.94 ms^{-1}] X_2=-0.684 [32.7 kg min^{-1}] X_3=0.181 [2.1°]	CV=11.463 %	14.81 13.30 11.68	0.92 0.93 0.96
Skewing ratio model (Equation 5)	X_1=-0.705 [14.95 ms^{-1}] X_2=0.263 [46.9 kg min^{-1}] X_3=-0.352 [-4.2°]	Skewing ratio: 0.994	13.88 13.10 13.65	0.90 0.98 0.96
Skewing ratio model (Equation 5)	X_1=-0.5663 [15.39 ms^{-1}] X_2=-0.561 [34.5 kg min^{-1}] X_3=-0.1 [-1.2°]	Skewing ratio: 0.993	16.37 14.15 15.57	0.91 0.90 0.99

*Swath width in all verification tests was found to be 10.16 m

Table 6. Verification test* results for TSP

Model	Variables	Calculated performance values from the equations	CV values obtained from the verification tests** (three replications)	Skewing ratio values obtained from the verification tests (three replications)
CV % Model (Equation 6)	X_1=0.581 [19.06 ms^{-1}] X_2=0.633 [52.5 kg min^{-1}] X_3=-0.282 [-3.3°]	CV=20.29 %	19.63 20.05 17.46	0.81 0.75 0.85
Skewing ratio model (Equation 7)	X_1=-0.555 [15.43 ms^{-1}] X_2=0 [43 kg min^{-1}] X_3=-0.435 [-5.2°]	Skewing ratio:0.892	18.20 18.00 15.90	0.77 0.77 0.81

*Swath width in all verification tests was found to be 10.16 m, **One set of optimum level of the variables was tested since optimum level of the variables given in Table 6 are similar.

CONCLUSIONS

This study demonstrated that the impeller angle is a significant constructional variable while the two operational related variables (disc peripheral speed and flow rate) affect the distribution uniformity. The CV (%) and skewing ratio as the indicators of the distribution uniformity are very sensitive and vary within a wide range once a small change is made in impeller angle.

The performance tests for any manufactured fertilizer distributor can be tested by conducting an RSM based study since standard test procedures may not help finding the optimum level of the variables that result in finding the acceptable levels of CV (%) and skewing ratio.

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