

Optimization of Design Parameters of Press Wheel Attached Straw Cutting Mechanism for Rice Residue in Simulated Field Condition

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The main challenge with conservation tillage methods, such as no-tillage and minimum tillage planting is placing seeds beneath crop residue with proper seed-soil contact. Sowing technologies in conservation tillage can improve soil quality, reduce erosion, and save time and fuel. However, crop seed germination is negatively affected by plant residues on the soil surface, so these residues must be managed. To overcome this problem, three types of coulter blades were tested in a soil bin to assess their ability to cut paddy residue, considering factors such as speed ratio and the number of press wheels. Horizontal and vertical forces, torque applied, and power requirements were calculated for selected blades at different speed ratios, numbers of press wheels, and different levels of rice residue during operations. Various parameters, such as the type of cutting coulter blades, speed ratio, number of press wheels, and different levels of rice residue density, were optimized to achieve maximum paddy residue cutting efficiency and minimum straw clogging. The optimized values of horizontal force (12.88 kg), vertical force (33.45 kg), torque applied (12.48 Nm), and power requirement (310.6 W) were obtained at the optimal design parameters: speed ratio (7.70), number of press wheels (2), and straw density (500 kg/ha). The maximum cutting efficiency of 100% and the minimum straw clogging of 1.80 kg/ha were achieved for a plain coulter blade.

Keywords: Conservation tillage, Coulter blades, Press wheel, Straw cutting efficiency

Introduction

In India, the practice of burning crop residue after harvest is a significant contributor to air pollution. To expedite field clearance for the next planting season, farmers frequently set fire to leftover rice straw and stubble that residue burning contributes to greenhouse gas emissions, particularly carbon dioxide and methane including particulate matter and other harmful pollutant. It's estimated that burning crop residue releases 150 million tonne (Mt) of carbon dioxide (CO₂), over 9.0 Mt of carbon monoxide (CO), 0.25 Mt of sulphur oxides (SO_x), 1.30 Mt of particulate matter, and 0.07 Mt of black carbon annually.¹ These emissions directly contribute to environmental pollution, haze in Delhi, and the melting of Himalayan glaciers.^{1,2} According to the Indian Ministry of New and Renewable Energy (MNRE), India produces over 500 Mt of crop residue annually. After using some of it for fodder and fuel, a surplus of 140 Mt remains, with 92 Mt burned each year.^{3,4} Proper residue management helps farmers reduce air pollution and mitigate climate change. By

avoiding burning crop residues and adopting techniques that promote decomposition and soil incorporation, farmers can sequester carbon, reduce agriculture's carbon footprint, and enhance climate resilience.

Many researchers have tried to improve the performance of no-till sowing machines by modifying the furrow openers, coulter size and shapes, coulter driving arrangements, and ground clearance of tynes. However, these modifications have not been successful in meeting all the agro-technical requirements for seed planting.⁵⁻¹³ They have found that smooth, toothed, notched, ripple, and wave disc coulters are utilized for the tasks such as seed line formation, plant residue cutting, and seed planting in no-till sowing. However, these coulters often fail to meet all of the required agricultural specifications during seed planting.

The evaluation of smooth, notched, and toothed disc coulters was done. The results showed that the smooth coulter exhibited the lowest performance in terms of horizontal forces, vertical forces, rolling resistance, and residue cutting percentage in a soil bin.⁵ Furthermore, it was determined that the toothed coulter effectively cuts the sugarcane residue at a

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depth of 80 mm. The efficiency of notched and smooth coulters in cutting wheat residue in a no-tillage system was assessed.¹⁴ They found that the notched disc coulters were more effective at cutting wheat residue than the smooth disc coulters. The draft requirements and residue cutting performances of disc openers of various sizes were assessed under no-till paddy soil conditions. The results indicated that the disc opener with a diameter of 450 mm exhibited superior residue cutting efficiency, reaching 88.6% when operated at a depth of 90 mm.¹⁰ The performance of four different types of disc coulters (helical, wavy, rippled and plain) was compared wheat residue cutting at different speeds. The tractive force required increased with speed, with the plain disc coulters requiring the least mobilized area, followed by the helical, wavy, rippled and plain disc coulters. The findings of this study suggest that the plain disc coulters are the most efficient type of disc coulters for cutting wheat residue.^{14,15} The performance of soil and corn residue cutting was compared using various discs in a soil bin setup. It was found that the working depth had a greater effect on disc performance than the type of disc itself.

Previous studies primarily focused on investigating the cutting of plant residues using inactive disc coulters, while studies evaluating active disc coulters are needed.^{12,16,17} The shape of the disc highly influences residue cutting effectiveness. However, some reports suggest that different disc shapes such as rippled, smooth, notched and fluted and exhibit similar performance in residue shearing.^{17,18} The cutting efficiency is related to the type of coulters blade being used, its shape, soil conditions, moisture conditions, and type of crop residue. No study has been conducted in Indian soil with the incorporation of a press wheel with coulters blades. To address this issue, a study was undertaken to assess the performance of a coulters-based cutting device for rice residue under field-simulated conditions in a soil bin. The goal was to optimize design parameters such as speed ratios, number of press wheels, straw densities, and blade types to enhance the cutting efficiency of the system for a coulters blades.

Material and Methods

Experimental Set up and Instrumentation

The research was conducted at the Soil Dynamic Laboratory located at coordinates 23°18'33.0"N and 77°24'7.0"E of ICAR-Central Institute of Agricultural Engineering in Bhopal, Madhya Pradesh.

The straw cutting device was mounted on the frame using a sub-frame, which was entirely supported by the carriage. Six strategically placed force transducers (IPA, Pvt. Ltd., Bangalore) were used to measure the horizontal and vertical forces exerted on the straw cutting mechanism. The mechanism was powered by a 5 hp motor, which transmitted power through a chain and sprocket setup. A torque sensor (SA-10, Sushama Industries, Bangalore) was attached to the motor's shaft. The RPM of the coulters was determined using a proximity switch. A comprehensive view of the experimental setup for the straw cutting mechanism is illustrated in Fig. 1 (a) and (b). Various types of straw cutting mechanisms, along with the press wheel unit (Fig. 2), were attached to the frame mounted on the front toolbar of the carriage, spanning the width of the bin. The dimensions of the coulters blades used in the straw cutting mechanism are listed in Table 1.

The soil in the soil bin was clay loam, composed of 47.5% sand, 23% silt, and 29.5% clay, and was prepared to simulate the field conditions for sowing. The soil compaction level was measured using a cone penetrometer (M1.06.15.SA.E, Eijkelkamp, AgriSearch Netherlands) of maximum range of 5000 kPa capacity. The penetration resistance of a near value of 1.40 MPa was maintained in the top 150 mm of soil depth with moisture content ranged between 20–22%. The residue cutting mechanism with seeding attachment carriage, was operated at 2.5 km/h speed, maintaining the depth of residue cutting of 15 mm.

Design of Experiments

The analysis considered various factors such as speed ratio, paddy straw density, press wheels and the type of cutting coulters blade. It examined their impacts on horizontal force (draft), vertical force, torque, power requirements, straw cutting efficiency and the incidence of straw clogging.

The levels of variables in both coded and actual units are presented in Table 2. Data analysis, statistical modelling and optimization were performed



Fig. 1 — Experimental set-up of straw cutting mechanism

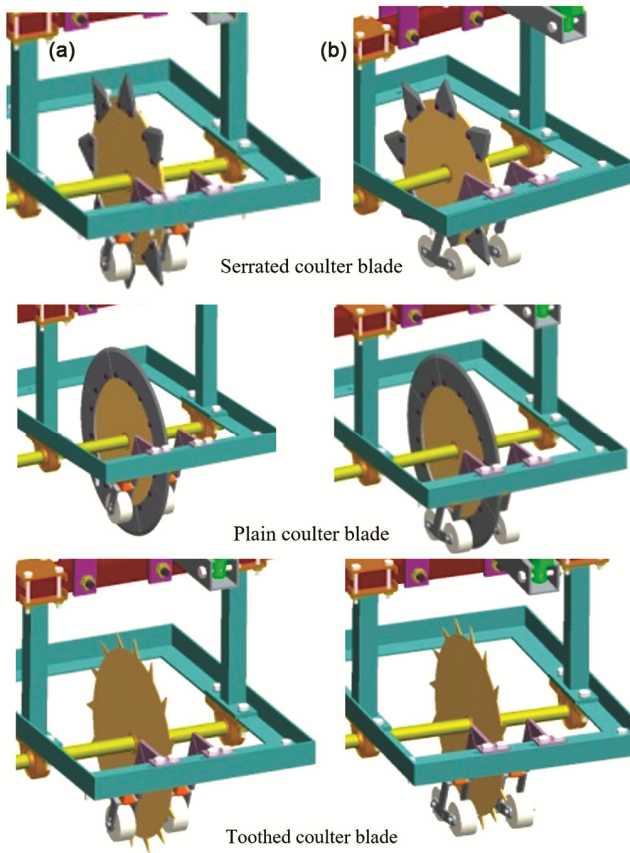


Fig. 2 — CAD view of different straw cutting devices, including serrated, plain, and toothed types (from top to bottom), equipped with (a) a pair of single press wheels and (b) a twin press wheel assembly (from left to right).

Table 1 — Specification of selected coulters blades

Type of blade (Nomenclature)	Serrated (B1)	Plain (B2)	Toothed (B3)
Outer diameter, mm	460	460	460
Thickness, mm	4	4	4
No. of blades/teeth	8/0	0/0	0/16

Table 2 — Levels, coded and interval of variation for operation of straw cutting mechanism in soil bin

Name of the variables	Code (X_i)	Levels			Intervals
		X_{i1}	X_{i2}	X_{i3}	
		-1	0	+1	
Speed ratio	X_1	5.2	6.935	8.67	1.735
Straw density (kg/ha)	X_2	3000	4000	5000	1000
Pair of press wheels (Nos.)	X_3	0	1	2	1
Type of blade	X_4	B1	B2	B3	—

using the Response Surface Method (RSM). The Optimal Custom Design with a Quadratic model was used. Experimental data regression analysis was conducted with Design Expert software (Version 13.0, Stat-Ease, Statistics Made Easy, Minneapolis, MN, USA). The study examined the relative effects of

the variables (speed ratio, pairs of press wheels, straw densities and types of blades) on the responses, and optimized the straw cutting parameters to achieve the best efficiency.

Data Analysis and Optimization

Regression analysis and ANOVA were employed to fit models and evaluate their statistical significance. Model adequacy was determined through model analysis and a lack of fit test. Response surfaces and contour plots were created using Design Expert software, which also conducted numerical optimization based on Eqs 1 and 2.

The actual levels of the independent variables were coded to simplify the analysis according to Eq. (1)⁽¹⁹⁾.

$$X_i = \frac{X_i - X_i^*}{\Delta X_i} \dots (1)$$

where, the dimensionless coded value X_i was related to the corresponding uncoded value X_i of the i^{th} independent variable. The uncoded value of the i^{th} independent variable was denoted by X_i^* at the center point.

Each response variable (Y_k) was modelled using the independent variables (X_i) through the following second-order polynomial response surface model using Eq. (2).

$$Y_k = b_{k0} + \sum_{i=1}^4 b_{ki} X_i + \sum_{i=1}^4 b_{kii} X_i^2 + \sum_{i=1, j=1}^4 b_{kij} X_i X_j \dots (2)$$

where, b_{k0} , b_{ki} , b_{kii} and b_{kij} represents the constant, linear, quadratic, and interaction regression coefficients, respectively, while X_i denotes the coded independent variables X_1, X_2, X_3 and X_4 .

Numerical optimization

Target for each factor and response were established, including goals such as maximizing, minimizing or maintaining within a specified range. Independent factors were constrained to their specified ranges, while responses were either maximized or minimized. To optimize multiple responses simultaneously, these goals were combined into a single composite function, $D(x)$, known as the desirability function, as defined by Eq. (3).⁽²⁰⁾ The desirability function is an objective measure ranging from 0 (least desirable) to 1 (most desirable). Numerical optimization maximizes this function, with goal characteristics adjustable by weight or importance.

$$D(x) = (d_1 x d_2 x \dots \dots x d_n)^{1/n} \dots (3)$$

where, d_1, d_2, \dots, d_n represent the desirability scores for each response, where n denotes the total number of responses being measured.

Measurement of Different Responses

The impact of different factors on the development of straw cutting mechanism, by measuring different forces, torque, and power required for straw cutting, as well as the straw cutting percentage and instances of straw clogging. The measurements of horizontal force, vertical force, and torque were directly recorded and saved in the computer system.

Different Forces and Torque Measurements

The instrumentation system was arranged to measure horizontal force (F_h), vertical force (F_v), and torque (T) acting on a tool in operation. Forces acting on a tool during operation were measured with the help of six S-type transducers (IPA, Pvt. Ltd., Bangalore). A separate provision was made for giving power to the straw cutting discs through the variable speed drive (VS-616 G5, Fukuoka, Japan) of capacity 20 kW. A torque transducer (SA-10, Sushama Industries, Bangalore) of capacity 100 Nm was coupled between the motor and the rotational cutting discs with the help of a coupling and locking bolt at one end and a chain-sprocket arrangement at the other end of the rotational disc shaft.

Percentage of Straw Cut and Clogged Straw Measurements

The percentage of straw cut by each disc was measured by weighing and counting uncut straw picked from the furrow. To simplify this process, 100 straw pieces of 400 mm length were spread at densities of 3000, 4000, and 5000 kg/ha on the test track. Clogged straw, sticking to wheels or gathering on the furrow opener and frame, was collected from a 2 m² area during the test run and weighed, with the amount expressed as kg/ha.

Validation of Straw Cutting Mechanism with Seed Drill Attachment

An optimized straw cutting device consisting of a plain blade disc and twin press wheels was tested for wheat sowing in a soil bin. The tests were conducted at optimal value of a speed ratio of 7.70 and a straw density of 5000 kg/ha. A seed drill attachment was mounted on the rear tool bar of carriage provided for mounting soil preparation equipment. Seeding attachment was also mounted behind the cutting mechanism to make them simulated to field condition and to check any mechanical blockage in front of

furrow opener. A view of straw cutting with seed drill attachment is shown in Fig. 3.

Results and Discussion

Effect of Different Independent Parameter on Horizontal Force (Draft) (F_h)

There is significant variation in horizontal force (F_h) due to changes in speed ratio, the use of twin press wheels, straw density, and blade type (Table 3). Horizontal force (Fig. 4a) increased linearly with increasing speed ratio, high straw density, and more number of press wheels. The horizontal force (F_h) increases with the speed ratio because the blades need to exert more effort and operate more efficiently at higher speeds, requiring additional force. Similarly, F_h increases with straw density due to the greater resistance and load posed by the denser material, necessitating more force to achieve effective cutting. Similar trend was achieved by the researcher.^{8,10} F_v values indicated that a pair of press wheels was the most influencing factor followed by type of blade. The speed ratio was the least influencing factor because straw density directly increases material resistance, having a more substantial impact on the horizontal force (F_h).

The equation expressed in terms of actual factors allows for predicting the response of F_h based on specified levels of each factor. The value of R^2 calculated using the least squares method, was found to be 0.99, indicating a strong fit of the model to the data. The regression Eqs (4–6) describe the impact of the variables on F_h for serrated (B1), plain (B2), and toothed (B3) blades, with the effects expressed in terms of the actual variable levels as follows.



Fig. 3 — View of straw cutting mechanism with seed drill attachment

Table 3 — ANOVA table for showing the effects of different factor on different response

Source	D _f	F-value					
		Horizontal force	Vertical force	Torque	Power	Straw Cut	Straw clogged
Model	17	202.69 ^S	366.27 ^S	203.54 ^S	568.37 ^S	22.74 ^S	28.29 ^S
X ₁ -Speed Ratios	1	37.29 ^S	30.32 ^S	36.84 ^S	36.47 ^S	0.57 ^{NS}	12.38 ^S
X ₂ -Straw Densities	1	103.69 ^S	424.66 ^S	158.96 ^S	2450.31 ^S	0.34 ^{NS}	11.08 ^S
X ₃ -Pair of Press Wheels	1	2197.66 ^S	3303.42 ^S	1284.16 ^S	1577.33 ^S	283.47 ^S	95.55 ^S
X ₄ -Blades	2	211.06 ^S	750.70 ^S	544.79 ^S	1234.14 ^S	8.27 ^S	65.60 ^S
X ₁ X ₂	1	1.81 ^{NS}	0.0605 ^{NS}	4.02 ^{NS}	0.6425 ^{NS}	0.28 ^{NS}	3.89 ^{NS}
X ₁ X ₃	1	0.2614 ^{NS}	1.72 ^{NS}	9.62 ^S	0.0017 ^{NS}	0.11 ^{NS}	4.31 ^{NS}
X ₁ X ₄	2	1.28 ^{NS}	1.66 ^{NS}	1.50 ^{NS}	4.17 ^{NS}	0.50 ^{NS}	3.38 ^{NS}
X ₂ X ₃	1	2.75 ^{NS}	4.13 ^{NS}	0.9351 ^{NS}	159.86 ^S	0.01 ^{NS}	3.50 ^{NS}
X ₂ X ₄	2	19.04 ^S	4.11 ^S	69.40 ^S	171.59 ^S	0.24 ^{NS}	7.15 ^S
X ₃ X ₄	2	0.1859 ^{NS}	2.32 ^{NS}	32.80 ^S	5.38 ^S	3.86 ^{NS}	5.32 ^{NS}
X ₁ ²	1	8.32 ^{NS}	2.18 ^{NS}	0.1046 ^{NS}	15.84 ^S	10.44 ^S	0.099 ^{NS}
X ₂ ²	1	1.24 ^{NS}	0.95 ^{NS}	3.35 ^{NS}	9.56 ^S	1.96 ^{NS}	9.32 ^S
X ₃ ²	1	12.46 ^{NS}	58.94 ^S	6.53 ^S	86.20 ^S	7.83 ^S	98.98 ^S
Residual	10						
Lack of Fit	5	1.12 ^{NS}	1.52 ^{NS}	1.89 ^{NS}	2.25 ^{NS}	0.70 ^{NS}	4.85 ^{NS}
Pure Error	5						
Cor Total	27						

S- Significant, NS- Not significant

Equation for plain blade (B1)

$$\text{Horizontal force} = 2.22 + 1.04 X_1 + 0.0033 X_2 + 1.58 X_3 \quad \dots (4)$$

Equation for plain blade (B2)

$$\text{Horizontal force} = 5.11 + 1.20 X_1 + 0.0021 X_2 + 1.67 X_3 \quad \dots (5)$$

Equation for toothed blade (B3)

$$\text{Horizontal force} = 4.35 + 1.11 X_1 + 0.0028 X_2 + 1.71 X_3 \quad \dots (6)$$

Effect of Different Independent Parameter on Vertical Force Evaluation (F_v)

ANOVA was conducted to assess the effect of various variables on F_v, as detailed in Table 3. The model's F-value of 366.27 indicates a significant model fit. Significant variations in F_v were observed with changes in speed ratio, straw density, type of blade and the number of press wheels (Fig. 4b). Specifically, increasing the speed ratio from 5.20 to 8.67 led to higher F_v for all three types of straw cutting blades, across all straw densities and with an increase in the number of press wheels from 0 to 2. The F-values demonstrated that the number of press wheels had the greatest influence on F_v followed by blade type. In contrast, the speed ratio had the least effect, while straw density had a moderate impact on F_v. This is due to the mechanical system is designed

such that it handles changes in speed ratio more efficiently, thereby showing less variation in vertical force. Conversely, it might be more sensitive to changes in straw density due to the direct impact on the cutting process. A similar trend was achieved and reported by the researcher in their findings.^{5,9,10}

The F_v increased linearly with increased speed ratios and straw densities while it decreased quadratically with a pair of press wheels. The R² value of 0.99 indicates an excellent fit of the model to the data. The regression Eqs (7–9) outline the effects of the variables on F_v based on their actual levels, as presented below.

Equation for serrated blade (B1)

$$\text{Vertical force} = 10.47 + 1.86 X_1 + 0.0011X_2 + 9.24X_3 - 1.65X_3^2 \quad \dots (7)$$

Equation for plain blade (B2)

$$\text{Vertical force} = 3.82 + 2.05 X_1 + 0.00027 X_2 + 9.43 X_3 - 1.65X_3^2 \quad \dots (8)$$

Equation for toothed blade (B3)

$$\text{Vertical force} = 8.08 + 1.73 X_1 + 0.001 X_2 + 9.99X_3 - 1.65X_3^2 \quad \dots (9)$$

Effect of Different Independent Parameter on Torque Applied

The ANOVA (Table 3) showed significant variation in torque with changes in speed ratio, press

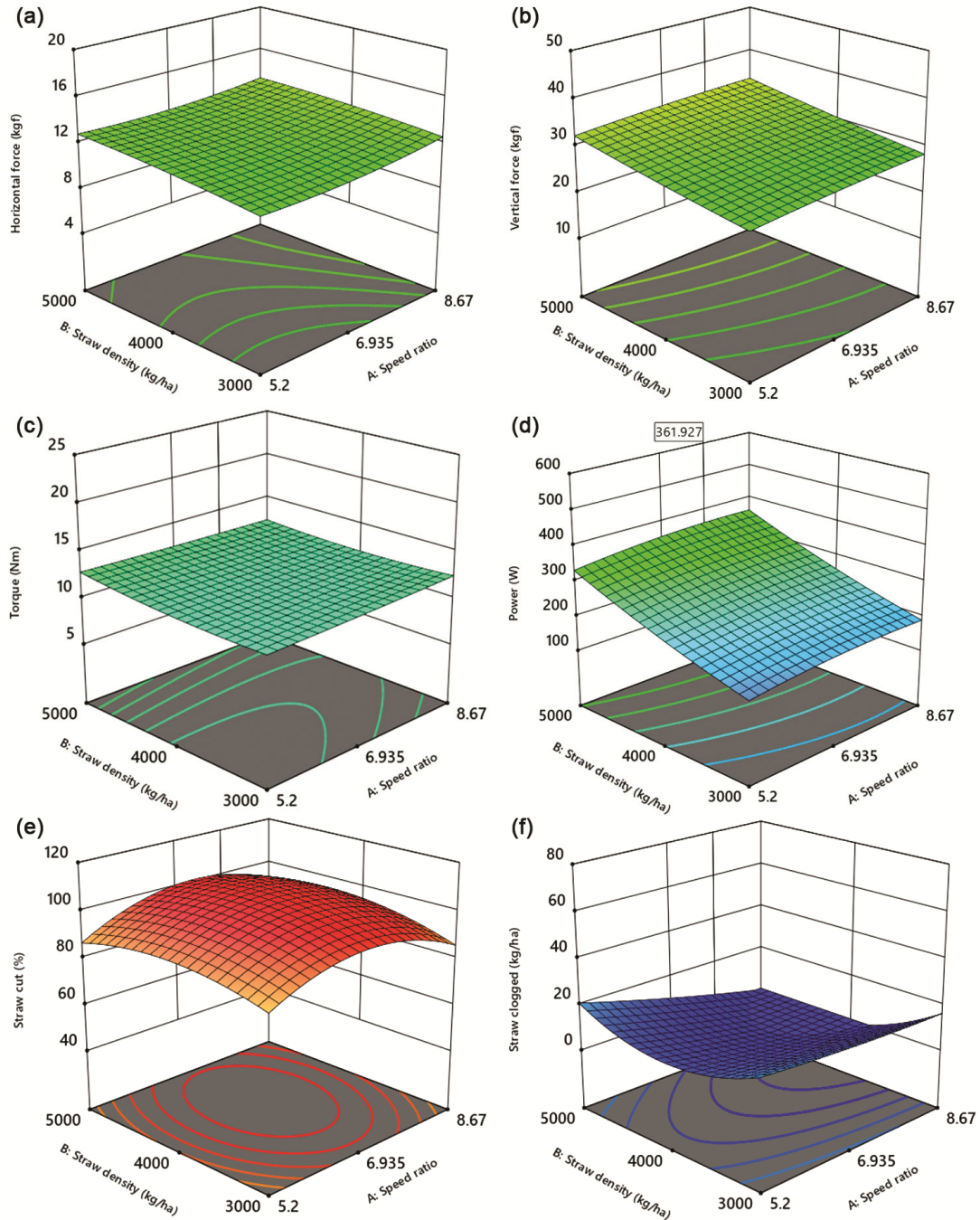


Fig. 4 — Contours plot for (a) horizontal force, (b) vertical force, (c) torque, (d) power requirement, (e) straw cut percentage and (f) clogged straw for straw cutting at varying speed ratio and a pair of press wheels and straw densities

wheels, straw density, and blade type ($P < 0.001$). The linear terms speed ratio, straw density and pair of press wheels and quadratic terms a pair of press wheels are significant ($P < 0.05$). The torque requirement was most influenced by a pair of press wheels, followed by the type of blade, with straw density having a moderate effect and speed ratio

having the least influence. The speed ratio primarily enhances cutting efficiency and reduces resistance to some extent, but its influence on torque is limited once an optimal speed is achieved. In contrast, straw density consistently and proportionally increases resistance, making it a more significant factor in determining the torque requirement.

The equation predicts responses accurately, with an R^2 of 0.99. Torque requirements increase linearly with speed ratio, number of press wheels and straw density and increased quadratically with press wheels for all blades (Fig. 4c). The relationships between the torque requirement and the variables (speed ratio, straw densities, and No. of pair of press wheels) are shaped by the physical and mechanical interactions between the blades and the straw. The addition of press wheels with higher straw density increase resistance due to compounded friction and compression effects. The regression Eqs (10–12) detailing the impact of variables on torque, based on their actual levels is provided as follows:

Equation for serrated blade (B1)

$$\text{Torque} = -0.58 + 1.04 X_1 + 0.001 X_2 + 3.68X_3 + 0.47X_3^2 \quad \dots (10)$$

Equation for plain blade (B2)

$$\text{Torque} = 6.62 + 0.81 X_1 + 0.02 X_2 + 2.84 X_3 + 0.47X_1^2 \quad \dots (11)$$

Equation for toothed blade (B3)

$$\text{Torque} = -0.18 + 0.87 X_1 + 0.0004 X_2 + 4.97 X_3 + 0.46X_1^2 \quad \dots (12)$$

Effect of Different Independent Parameter on Power Requirement

Significant variations in power requirements (Fig. 4d) were observed with changes in speed ratio, press wheels, straw density and blade type ($P < 0.001$) as per Table 3. The F-values showed that straw density was the most influential factor on power requirement, followed by a pair of press wheels, with the speed ratio having the least influence and the type of blade having a moderate effect. Higher straw density likely increases resistance to cutting, requiring more power for efficient operation. In contrast, variations in speed ratio have a smaller impact because the system is designed to function efficiently at various speeds, reducing its effect on power requirements.

The regression equations Eqs (13–15) illustrate the influence of variables on power requirements for different coulters blades, based on their actual levels. The model demonstrated a strong fit to the data, with an R^2 value of 0.99.

Equation for serrated blade (B1)

$$\text{Power} = -138.74 + 45.52 X_1 + 0.02 X_2 - 96.21 X_3 - 0.05X_1X_3 + 0.26 X_2X_3 - 3.43X_1^2 + 25.82X_3^2 \quad \dots (13)$$

Equation for plain blade (B2)

$$\text{Power} = -27.61 + 51.61 X_1 + 0.05 X_2 - 93.93X_3 + 0.05X_1X_3 + 0.26 X_2X_3 - 3.43X_1^2 + 25.82X_3^2 \quad \dots (14)$$

Equation for plain blade (B3)

$$\text{Power} = 4.52 + 48.92 X_1 + 0.025 X_2 - 81.86 X_3 + 0.05X_1X_3 + 0.26 X_2X_3 - 3.43X_1^2 + 25.82X_3^2 \quad \dots (15)$$

Effect of Different Independent Parameter on Straw Cut

It has seen (Table 3) that there was significant variation in the percentage of straw cut (Fig. 4e) with change in speed ratio and press wheel. The pair of press wheels was the most influencing factor (F value = 283.47) on straw cutting percentage because they play a crucial role in stabilizing and compressing the straw during the cutting process. By holding the straw firmly in place, the press wheels ensure that the blades can cut through the straw more effectively and consistently. This increased compression and stability reduce movement and allow for cleaner cuts, thereby significantly improving the percentage of straw cut. A comparable trend was observed and reported by the researcher.⁵ Another study also reported that the star wheel disc coulters exhibited the highest mean residue cutting at 98.15%, surpassing the curved teeth (76%), plain (62%), notched (84%) and cutter bar blade disc coulters (52%) when no residue holding devices were used.²¹ Conversely, some researchers have reported contrasting results regarding the cutting performance of the plain coulters.^{9,10,12}

The framework for predicting responses based on specified levels of each factor is provided by Eqs (16–18). With an R^2 value of 0.97, the model demonstrates a strong fit to the data. These equations describe the regression relationships for different blade types.

Equation for serrated blade (B1)

$$\text{Straw cut} = -223.14 + 49.35 X_1 + 10.32X_3^2 \dots (16)$$

Equation for plain blade (B2)

$$\text{Straw cut} = -211.21 + 45.92 X_1 + 10.32X_3^2 \quad \dots (17)$$

Equation for toothed blade (B3)

$$\text{Straw cut} = -215.21 + 49.35 X_1 + 10.32X_3^2 \quad \dots (18)$$

Effect of Different Independent Parameter on Clogged Straw

The significant variation in the clogged straw (Fig. 4f) with change in speed ratio, straw density and a pair of press wheels was observed (Table 3). The F-values indicated that type of blade was the most influencing over clogged straw whereas speed ratio was least influencing on clogged straw. The type of

blade significantly affects straw clogging because different blades cut the straw differently. Blades that cut poorly produce more fragments and uncut straw, which leads to increased clogging. In another study, the use of a power-driven disc-type rotary residue manager reduced straw clogging by 33%, facilitating easier wheat sowing under challenging conditions and minimizing interference with no-till drills.²²

The R² value calculated using the least squares method, was 0.98, indicating an excellent fit of the model to the data. Regression Eqs (19–21) detail the effects of variables on clogged straw, based on their actual levels.

Equation for serrated blade (B1)
 Straw clogged = 112.35 + 1.35 X₁ - 0.05X₂ + 85.42X₃ + 0.000011X₂² - 29.95X₃² ... (19)

Equation for plain blade (B2)
 Straw clogged = 112.35 + 1.35 X₁ - 0.05X₂ + 85.42X₃ + 0.000011X₂² - 29.95X₃² ... (20)

Equation for toothed blade (B3)
 Straw clogged = 129.49 + 6.72 X₁ - 0.06X₂ + 75.81X₃ + 0.000011X₂² - 29.95X₃² ... (21)

Optimization of Design Parameters for Development of Straw Cutting Mechanism

Desired goals for each factor and response were specified, as detailed in Table 4. Optimal conditions for the independent variables along with their predicted response values generated by the software which is shown in Table 5. The optimal condition for the straw cutting mechanism was determined to be Solution number 1, which achieved the highest

desirability score of 0.831. This solution resulted in minimal straw clogging at a rate of 1.80 kg/ha and 100% straw cutting. Numerical optimization resulted that the best combination for achieving 100% efficiency in cutting straw was obtained with a speed ratio of 7.70, utilizing a pair of press wheels and a plain-type coulter blade, while maintaining a straw density of 5000 kg/ha.

Validation of Model for Straw Cutting in the Soil Bin

The straw cutting mechanism experiments were conducted under optimal conditions to assess the performance of the straw cutting blade. The plain disc coulter, paired with press wheels, achieved 100% cutting efficiency as illustrated in Fig. 5. The experimental values and the model-predicted values are shown in Table 6. The predicted values fell within an acceptable range of 0 to 10% variation from the experimental values for horizontal force (F_h), vertical force (F_v), torque, power requirement, percentage of

Table 4 — Optimization criteria for various variables and responses related to the straw cutting mechanism

Name	Goal	Lower Limit	Upper Limit
Speed ratio	is in range	5.2	8.67
Straw density (kg/ha)	is in range	3000	5000
Pair of press wheels, (Nos.)	is in range	0	2
Type of blade	is in range	B1	B3
Horizontal force (kgf)	is in range	10	15
Vertical force (kgf)	is in range	25	35
Torque (Nm)	is in range	10	15
Power (W)	is in range	250	600
Straw cut (%)	maximize	75	100
Straw clogged (kg/ha)	minimize	3	10

Table 5 — Optimal conditions for the straw cutting mechanism determined by the software-generated solutions

No.	Speed ratio	Pair of press wheels	Straw density, kg/ha	Type of blade	F _h , kgf	F _v , kgf	Torque, Nm	Power, W	Straw cut, %	Straw clogged, kg/ha	Desirability
1	7.74	2.00	5000	B2	12.88	33.45	12.48	310.6	100	1.80	0.831



Fig. 5 — 100 % cutting achieved by plain disc coulter with pair of press wheels

Table 6 — Comparison of predicted and actual responses of the variables under optimal conditions for the straw cutting mechanism

Response	Predicted value	Mean predicted actual value	Variation, %
Horizontal force (kgf)	12.88	12.97	0.70
Vertical force (kgf)	33.45	31.36	6.66
Torque (Nm)	12.48	13.47	7.35
Power (W)	310.6	282.07	9.20
Straw cut (%)	100	100	0.00
Straw clogged (kg/ha)	1.80	1.67	7.22

straw cut, and clogged straw, demonstrating the validity of the models.

Conclusions

The maximum cutting efficiency of crop residue was achieved with a plain disc coulters at an optimized speed ratio of 7.70 and a pair of twin press wheels, using a straw density of 5000 kg/ha. The optimal values observed were 12.88 kg for horizontal force, 33.45 kg for vertical force, 12.47 Nm for torque, and 313.6 W for power requirement, all measured at a speed ratio of 7.70 with the pair of press wheels and straw density of 5000 kg/ha. This setup resulted in 100% cutting efficiency and a minimal straw clogging of 1.80 kg/ha. The plain coulters blade effectively cuts straw, while the twin press wheels enhance cutting efficiency by compressing the straw before it is cut. The performance of this mechanism may be ascertained by conducting long-term evaluations to assess the durability and maintenance requirements of the plain disc coulters and twin press wheels under continuous use.

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