Indian Journal of Ecology (2025) 52(5): 1071-1076
DOI: https://doi.org/10.55362/IJE/2025/4618

Manuscript Number: 4618
NAAS Rating: 5.38

Performance Assessment of Disc-Type Furrow Openers in Residue-Retentive Soils under Conservation Tillage

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Abstract: Effective residue management is essential for successful conservation tillage, especially in rice–wheat systems where combine harvesting leaves substantial straw on the surface. This study aimed to compare the performance of two disc-type furrow openers—single disc (SD) and double disc (DD)—in terms of straw-cutting efficiency and draft force under controlled soil bin conditions. Trials were conducted using loamy soil prepared to match field moisture content and compaction. Freshly harvested rice straw was spread uniformly at three densities (1, 2, and 3 t/ha), and the openers were tested at forward speeds of 1.5, 2.0, and 2.5 km/h, maintaining a working depth of 5 cm. The double disc opener consistently outperformed the single disc in cutting efficiency, achieving a maximum of 81.36% at 1.5 km/h forward speed. However, this came with a higher draft requirement, averaging 368.5 N under optimal conditions, the single disc required less draft force but showed reduced cutting performance, particularly at higher speeds and residue levels. Statistical analysis confirmed that furrow opener type, speed, and residue density significantly affected both draft force and straw-cutting efficiency. Overall, the double disc furrow opener was more effective for high-residue conservation tillage, offering a better balance between cutting performance and manageable draft force.

Keywords: Conservation tillage, Furrow opener, Double disc, Straw cutting efficiency, Draft force, Residue management

Conservation tillage is increasingly recognized as a sustainable agricultural practice aimed at minimizing soil disturbance, enhancing organic matter retention, and improving water conservation (Kolesnikov 2020, Francaviglia et al., 2023). It offers several agronomic and environmental advantages, such as reduced erosion, improved soil structure, and better moisture infiltration (Busari et al., 2015, Boincean et al., 2019). However, the retention of crop residues on the soil surface, a cornerstone of conservation tillage, poses operational challenges during sowing, especially in the rice–wheat cropping systems predominant in the Indo-Gangetic Plains (Singh et al., 2022, Leharwan et al., 2023). In these systems, combine harvesters are widely used, leaving a substantial layer of straw residues behind. This surface residue can obstruct furrow formation, cause seed placement issues, and increase the risk of "hair pinning," where straw is pushed into the furrow instead of being cut cleanly (Evans et al., 2009, Kumar et al., 2024). As a result, effective residue management becomes a prerequisite for successful seeding in conservation tillage.

Furrow openers play a central role in addressing this challenge. They are responsible for cutting through surface residue, creating a uniform furrow, and facilitating accurate seed placement—all with minimal soil disruption (Barr et al., 2016, Aikins et al., 2018, Madhusudan and Preetham 2020). Among various designs available, disc-type furrow openers are particularly suitable for conservation tillage because of their rolling action and capacity to slice through residue with less soil inversion. Of these, the single disc (SD) and double disc (DD) openers are the most used (Ahmad et al., 2017, Madhusudan et al., 2024). The SD opener, consisting of a single angled cutting disc, is known for its low draft requirements and narrow furrow profile. It is often used in dry and moderately compacted soils where minimal disturbance is desired. DD opener utilizes two angled discs to create a V-shaped furrow (Ahmad et al., 2017, Rathod et al., 2024). Its design tends to generate greater downward and lateral cutting forces, making it more effective in managing surface straw, especially under high-residue conditions. However, it also typically requires more draft power than the SD opener (Aikins et al., 2018). While both designs are widely implemented in the field, few studies have conducted a detailed mechanical comparison under controlled conditions. Most evaluations are carried out under open-field settings, where factors like uneven residue distribution, soil heterogeneity, and inconsistent moisture make it difficult to isolate the effects of tool geometry and operating parameters. soil bin environment offers a unique advantage in this context, allowing for the controlled study of furrow opener performance across variables such as forward speed and straw density. This study aims to assess and compare the relative performance of SD and DD furrow openers under simulated soil bin conditions.

MATERIAL AND METHODS

Experimental site and soil bin setup: The study was conducted during 2023-24 in the Soil Dynamics Laboratory of the Division of Agricultural Engineering at ICAR–Indian Agricultural Research Institute (IARI), New Delhi. The experiments were performed in a soil bin with dimensions of 25 m in length, 1.8 m in width, and 1 m in depth. The soil type in the bin was sandy loam with a composition of 80% sand, 10% silt, and 10% clay. Before each experimental run, the bin was tilled, leveled, and compacted using a 1015 kg cylindrical roller to standardize soil conditions across trials. The moisture content, bulk density, and cone penetration resistance were adjusted and maintained at 12% (dry basis), 1.5 g/cm³, and 1.45 MPa, respectively, to simulate post-harvest field conditions in Indo-Gangetic Plains. These parameters were validated by oven-drying soil samples at 105°C and using a digital cone penetrometer (Gilson HM-559A) with a 60° cone angle.

Furrow openers and frame setup: Two disc-type furrow openers were selected for the study: the Single Disc (SD) and the Double Disc (DD) openers (Fig. 1). The SD opener consisted of a high-carbon steel disc of 350 mm diameter set at a 12° tilt to the vertical to reduce soil disturbance while cutting through surface residue. The DD opener comprised two plain rolling discs of the same size, angled to form a V-shaped furrow. Both openers were mounted on a steel frame equipped with a depth adjustment mechanism and fixed at a working depth of 5 cm.

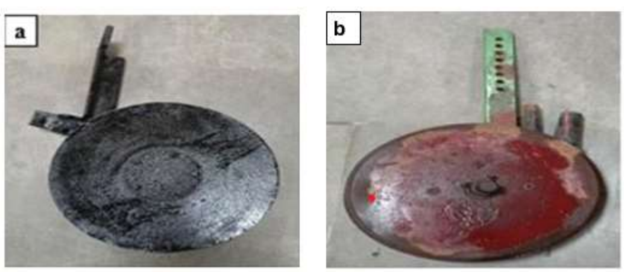

Fig. 1. Various furrow openers used for experimentation: **(a)** single disc (SD) furrow opener, **(b)** double disc (DD) furrow opener

Straw preparation and experimental conditions: Rice straw, collected post-harvest from a combine-operated paddy field, was uniformly spread over the soil surface in the bin at three different densities: 1, 2, and 3 t/ha (Fig. 2). The straw moisture content was approximately 18% (wet basis), and spreading was done manually to achieve uniform coverage. Each furrow opener was tested at three forward speeds (1.5, 2.0, and 2.5 km/h) using a motorized trolley mounted on rails alongside the soil bin. This speed range represents typical operational speeds for seed drills and no-till planters in conservation tillage.

Draft force measurement: Draft force was measured using a calibrated S-type load cell (GUANG CE YZC-516C, 1960 N capacity) placed between the furrow opener frame and the drawbar of the trolley (Fig. 3). The force signal was captured in real-time using an Arduino-based data acquisition system and visualized using serial oscilloscope software. The peak steady-state force during the 2-meter test section was recorded as the draft requirement.

Straw cutting efficiency: After each test run, the soil surface was carefully examined, and the straw was collected and separated into cut and uncut fractions. The uncut straw was weighed using a precision digital scale, and the cutting efficiency was calculated (Dong et al., 2013).

$$\text{Straw cutting efficiency (\%)} = 100 - \frac{\text{Weight of uncut straw}}{\text{Total straw weight}} \times 100$$

Three replications were performed for each combination of furrow opener type, speed, and straw density.

Statistical analysis: The collected data on draft force and straw-cutting efficiency were analyzed using two-way ANOVA to determine the main and interaction effects of furrow opener type and forward speed (or straw density). For multiple comparisons among group means, Tukey's Honest Significant Difference (HSD) test was used at a 5% significance level. Statistical analyses were performed using SPSS v25 and R software.

Fig. 2. Soil bin with straw cover

RESULTS AND DISCUSSION

The comparative assessment of single disc (SD) and double disc (DD) furrow openers revealed distinct performance trends under varying forward speeds and straw residue densities. Both furrow opener type and forward speed had a statistically significant influence on draft force while their interaction was not significant (Table 2). The draft force increased with increasing both forward speed and straw density for both furrow openers. At 1.5 km/h, the SD furrow opener recorded an average draft force of approximately 275 N, which rose to about 390 N at 2.5 km/h. Similarly, the DD furrow opener required more draft throughout the speed range, starting from 325 N and increasing to around 435 N at the highest speed (Fig. 4). The higher draft associated with the DD furrow opener is attributable to its dual-disc configuration, which engages more soil and residue compared to the SD furrow opener design. Sahu and Raheman (2006) also reported a similar relationship between operational speed and draft force, largely due to increased soil resistance and tool acceleration.

Straw cutting efficiency results followed a different pattern. The furrow opener type was the dominant factor influencing this parameter, with the DD furrow opener demonstrating significantly higher straw-cutting efficiency across all conditions (Table 2). At 1.5 km/h, the DD furrow opener achieved straw cutting efficiencies exceeding 80%, while the SD furrow opener managed around 65%. However, as forward speed increased, cutting performance declined

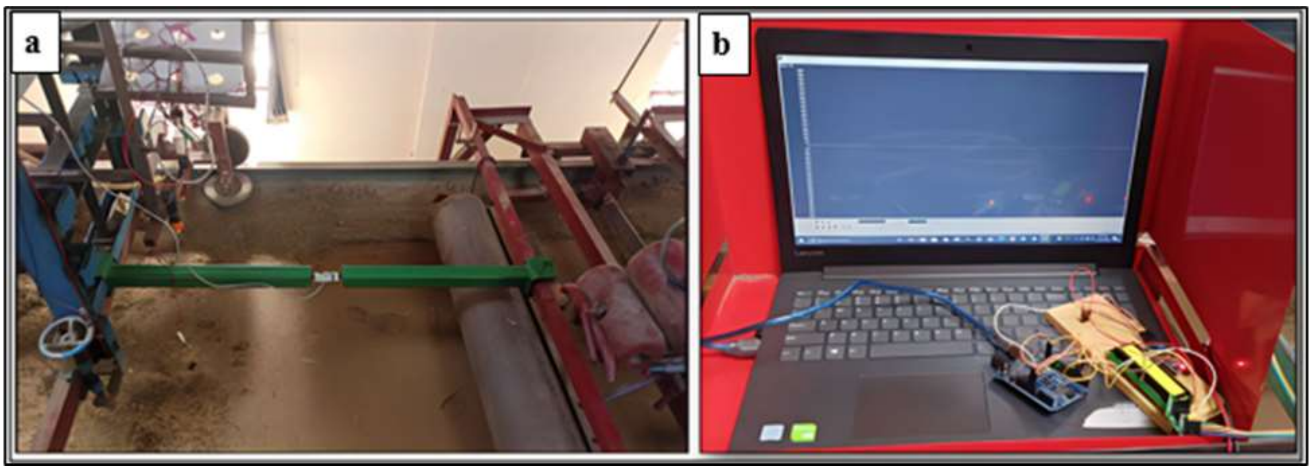

Fig. 3. Data acquisition setup (a) Load cell (b) Serial oscilloscope software

Table 1. Experimental plan for soil bin testing of furrow openers

Independent parameters	Levels	Dependent parameters
Furrow openers	2 i. Single disc furrow opener ii. Double disc type furrow opener	Draft force (N) Straw cutting efficiency (%)
Forward speed (km/h)	2 (1.5, 2 and 2.5)	
Straw density (t/ha)	2 (1, 2, and 3)	
Replications	2	

Table 2. Regression model for draft force requirement and straw cutting efficiency

Source of variation	df	Draft force				Straw cutting efficiency			
		SS	MS	F-value	p-value	SS	MS	F-value	p-value
Furrow Opener Type (A)	1	24570.5	24570.5	92.38	<0.001	4237.2	4237.2	116.96	<0.001**
Forward Speed (B)	2	48291.3	24145.7	90.83	<0.001	378.3	189.1	5.23	0.009*
Residue Density (C)	2	16852.7	8426.3	31.72	<0.001	281.5	140.75	3.88	0.029*
A × B Interaction	2	428.9	214.45	0.81	0.455	47.6	23.8	0.66	0.521
Error	36	9567.8	265.8			1302.7	36.2		
Total	43	99867.2				6247.3			

**, * indicate 1% and 5% level of significance, respectively for both furrow openers more for the SD furrow opener, whose efficiency dropped below 50% at 2.5 km/h (Fig. 2). These observations suggest that increased speed reduces the contact time between the opener and the straw, making it harder to sever residue, particularly for the single disc configuration which relies on a single point cutting action.

Similarly, straw residue density also had a clear effect on both draft force and straw cutting efficiency. The increasing the straw density from 1 to 3 t/ha led to a steady increase in draft requirements for both furrow openers (Fig. 5). The DD furrow opener exhibited a sharper increase in draft force with increase in residue density, indicating greater interaction between the furrow opener and the crop residue density. This reinforces the importance of considering residue load in equipment selection, particularly in conservation tillage systems where surface residue load is intentionally retained. In contrast, increasing the straw density reduces the straw cutting efficiency for both the furrow openers. The DD furrow opener demonstrated the highest cutting efficiency, exceeding 80%, while the SD furrow opener managed around 65%. The superior straw-cutting efficiency observed in the DD furrow opener is attributed to the result of applying a tensile force on both the straw and the soil (Ahmad et al., 2015, Xu et al., 2024). Additionally, the sticky nature of sandy loam soil in the soil bin led to a reduced occurrence of the hair pinning phenomenon in the DD furrow opener (Ahmad et al., 2015, Xu et al., 2024). Previous studies have also reported the superior performance of DD furrow openers in cutting deposited straw by employing a simple shearing and rolling action, with the soil acting as a counter knife (Aikins et al., 2018, Leharwan et al., 2023).

The interaction between forward speed and furrow

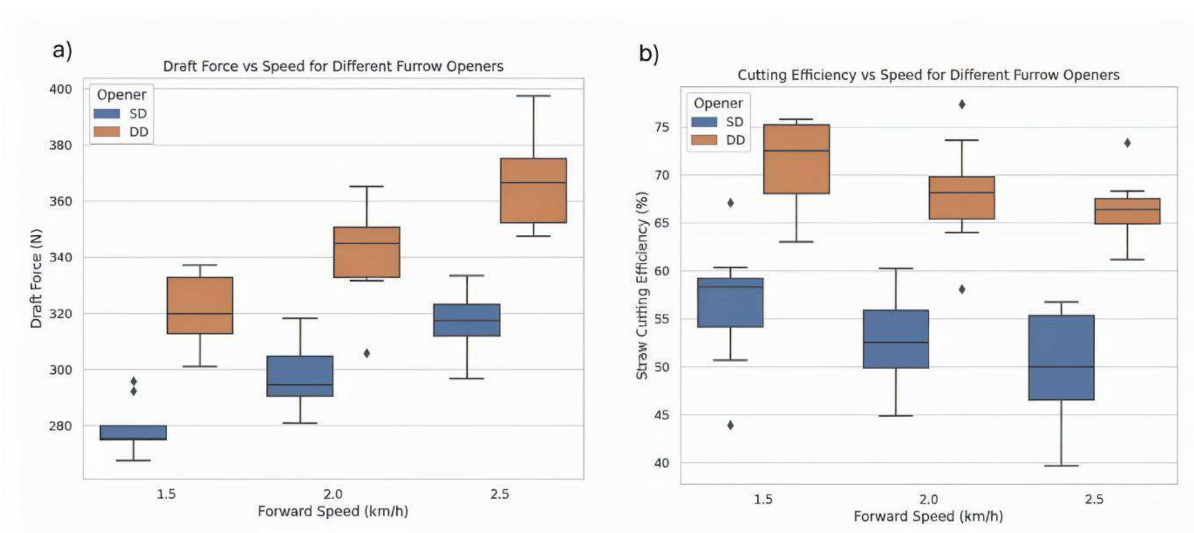

Fig. 4. Effect of forward speed and straw density on draft force for different furrow openers

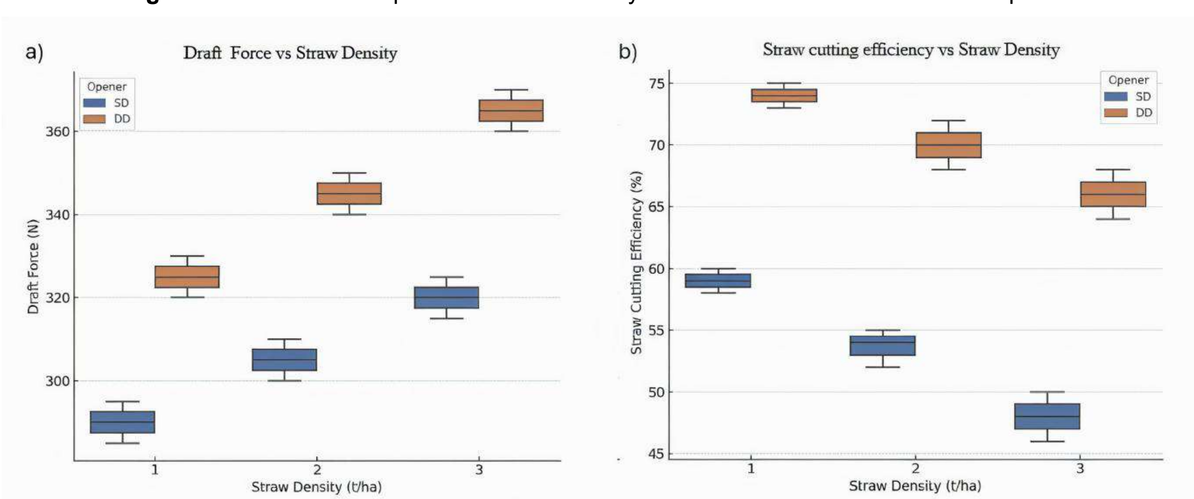

Fig. 5. Effect of forward speed and straw density straw cutting efficiency for different furrow openers

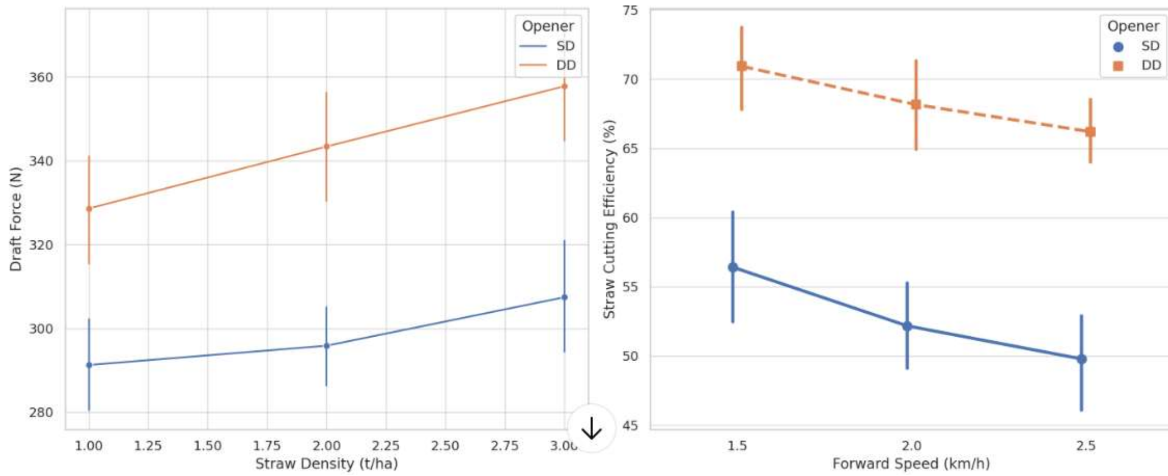

Fig. 6. Interactive effect of forward speed and furrow opener type on Draft force and straw cutting efficiency

opener type, though not statistically significant, revealed useful trends. the straw cutting efficiency of the SD furrow opener declined more steeply with forward speed than the DD furrow opener (Figure 6). This can be attributed to the DD furrow opener's symmetrical disc layout, which provides shearing force from both sides, improving its ability to slice through surface residue even at higher operational speeds. The SD opener, in contrast, lacks lateral engagement and tends to push straw into the furrow (hair pinning) at higher speeds. Aikins et al. (2018) and Leharwan et al. (2023,) also reported enhanced straw cutting and residue management with double disc openers in similar conservation tillage setups.

The results point to a clear trade-off between draft force and cutting efficiency. The SD furrow opener offers lower draft requirements, which could benefit small-scale or low-power tractors. However, it falls short in high-residue conditions and at higher speeds, where residue handling is critical. The DD furrow opener, while requiring more draft force, delivers superior straw cutting performance and maintains its efficiency more consistently across operational conditions. Based on these findings, the double disc furrow opener is better suited for conservation tillage applications, particularly where straw density exceeds 2 t/ha. For optimal performance, forward speeds should be maintained between 1.5 and 2.0 km/h to balance draft demand with effective residue cutting. These insights contribute to more informed machinery selection and operation strategies, ultimately supporting the wider adoption of sustainable residue-retentive farming practices.

CONCLUSION

This study provides a detailed comparison of single disc (SD) and double disc (DD) furrow openers under simulated conservation tillage conditions, focusing on their performance across different forward speeds and surface straw densities. both forward speed and straw residue density significantly affected draft force and straw-cutting efficiency. The DD furrow opener consistently achieved higher cutting efficiency, exceeding 80% at low speeds and residue levels, due to its symmetrical disc configuration and effective shearing action. However, this came with a higher draft requirement compared to the SD opener. The SD opener required less draft force, making it suitable for low-powered tractors, but its cutting efficiency declined significantly at higher speeds and straw densities. The interaction between forward speed and furrow opener type, while statistically non-significant, revealed that the DD opener maintained better efficiency across conditions, whereas the SD opener's performance deteriorated. The double disc furrow opener offered better cutting efficiency in high-residue conditions (>2 t/ha) but required higher draft force. Operating it at 1.5–2.0 km/h achieved an effective balance between residue management and energy use, supporting sustainable conservation tillage practices.

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Received 09 July, 2025; Accepted 23 September, 2025