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RESEARCH ARTICLE

Effect of rice residue and nitrogen management on weeds and productivity of oilseed rape (*Brassica napus* L.)

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ABSTRACT

A field experiment was conducted during the winter (*Rabi*) seasons of 2023-24 and 2024-25 at Punjab Agricultural University, Ludhiana, to evaluate the effects of rice residue and nitrogen management on weeds in oilseed rape (*Brassica napus* L.) of rice (*Oryza sativa* L.)- should be in the middle oilseed rape rotation. The experiment was laid out in a split-plot design with three replications. Main plot treatments included three rice residue management practices involving oilseed rape seeding with Happy seeder (Happy seeder), surface seeding-cum-mulching, and conventional method while the sub-plot treatments comprised of three nitrogen levels, *viz.* 75%, 100% and 125% of the recommended dose of nitrogen (RDN). Among the rice residue management practices, both the surface seeding-cum-mulching and Happy seeder method recorded significantly lower weed density and biomass compared to the conventional method at 30 days after sowing (DAS). Application of 75% RDN resulted in significantly lower weed density and biomass at 30 DAS compared with 100% and 125% RDN. Further, application of 125% RDN increased seed yield by 19.6% over 75% RDN, whereas 100% RDN produced a 15.3% higher yield than 75% RDN. The highest weed density and biomass were observed with the conventional method, indicating that residue retention practices using Happy seeder and surface seeding-cum-mulching methods, combined with 75% nitrogen dose were more effective in suppressing weed emergence and growth in oilseed rape based on the two-year pooled analysis. Happy seeder-sown oilseed rape produced 10.4% and 23.3% higher seed yield than conventional method and surface seeding-cum-mulching, respectively.

Keywords: Happy seeder, Nitrogen management, Surface seeding-cum-mulching, Weed management

INTRODUCTION

In northwest part of India, *Brassica napus* (oilseed rape/*gobhi sarson*) and *B. juncea* (mustard/*raya*) are grown on a commercial scale. In Punjab, oilseed rape, especially canola quality is exclusively grown under irrigated conditions while mustard is grown under both irrigated and rainfed conditions. Weed competition is one of the major constraints limiting the productivity of canola quality of oilseed rape. The crop-weed interference is severe particularly during the early growth period of 15 to 40 days after sowing (DAS), when the crop is highly sensitive to competition for light, moisture, and nutrients due to its short stature and wide row spaces of 45 cm (Yernaidu *et al.* 2024). Yield losses due to unchecked weed growth in rapeseed–mustard systems range from 25-50%, depending on weed flora, infestation intensity, and crop growth stage (Yadav *et al.* 2017). Traditionally, hand weeding has been the predominant weed control method in mustard; however, this practice is becoming unsustainable due to high labour costs, seasonal worker scarcity and the time and efforts required. Moreover, a single hand weeding at 25-30 DAS is often inadequate, as new weed flushes emerge after irrigation or winter rains, leading to renewed competition at later stages. The weed infestations deplete soil moisture and nutrients, reducing crop vigour and yield potential. Although herbicides are widely used, over-reliance on chemical control increases the risk of evolution of herbicide-tolerant weed species, especially under frequent or high-dose applications (Asaduzzaman *et al.* 2020). In addition, herbicides alone are often less effective against the diverse and dense weed populations found in mustard fields. Therefore, integrated weed management (IWM) strategies combining cultural, mechanical and chemical approaches are gaining importance. The rice residue retention as surface mulch has emerged as a promising component option of IWM.

The challenge in intensified in rice-mustard cropping systems is the large amount of rice residue left after rice combine harvesting, which typically leaves 30-40 cm stubbles and a thick rice straw layer. Rice residue burning, though common, is

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environmentally harmful, causing greenhouse gas emissions, nutrient loss and soil degradation (Bhuvaneshwari *et al.* 2019). The conservation agriculture practices involving residue retention and reduced tillage have shown potential to modify weed flora composition and reduce weed emergence in rice-based systems (Kaur *et al.* 2025, Sraw *et al.* 2025). The residue management strategies such as retention, incorporation, or mulching are being increasingly explored to enhance soil health and reduce weed infestation. The surface retention of rice residues acts as mulching material and affect soil microclimate including the microbial health, and thus affect the transformations of carbon, nitrogen and phosphorus in soil (Sraw *et al.* 2025).

Nitrogen management plays a crucial role in determining crop vigour, canopy structure, and competitive ability. Adequate nitrogen supply enhances crop photosynthetic efficiency, vegetative growth, and canopy closure, reducing light availability for weeds. Conversely, excessive nitrogen may favour certain weed species, intensifying competition. Although residue retention improves soil moisture and crop competitiveness, it also influences nutrient dynamics particularly nitrogen availability as microbial decomposition of residues can temporarily immobilize nitrogen, affecting both crop and weed growth. Keeping in view the advantages of residue retention on weed suppression, there is a need to evaluate the interactive effects of crop residues and nitrogen levels on weed growth. Understanding the interaction between nitrogen levels and residue management is vital for developing effective and sustainable weed management strategies in oilseed rape under rice-oilseed rape rotation. Therefore, this study was conducted to study the interactive effects of residue retention and nitrogen levels on weeds dynamics and productivity of oilseed rape.

MATERIALS AND METHODS

The field experiment was conducted at the Students' Research Farm, Punjab Agricultural University, Ludhiana, during the *Rabi* seasons of 2023-24 and 2024-25. The site is situated at 30°542 N latitude and 75°482 E longitude, at an elevation of 247 m above mean sea level, representing a semi-arid subtropical climate. The experimental soil was sandy loam in texture, medium in organic carbon (0.44%), available nitrogen (304 kg/ha), and available potassium (247 kg/ha), and high in available phosphorus (26.4 kg/ha). The soil pH was nearly neutral (7.36) with normal electrical conductivity (0.20 dS/m).

Meteorological data recorded at the Meteorological Observatory of Punjab Agricultural University, Ludhiana, during the 2023-24 and 2024-25 crop seasons are presented in **Figure 1**. In 2023-24, the weekly maximum temperature ranged from 11.4°C to 32.0°C, while the minimum temperature varied between 5.0°C and 17.0°C. The total rainfall during the season was 127.1 mm, with mean relative humidity between 53% and 87%, and total weekly sunshine hours ranging from 0.3 to 10.9 hours. During 2024-25, the weekly maximum temperature ranged from 11.0°C to 36.0°C, and the minimum temperature varied between 5.0°C and 17.0°C. The season received 127 mm of rainfall, with mean relative humidity ranging from 43% to 86.5%, and total sunshine hours between zero and 11 hours.

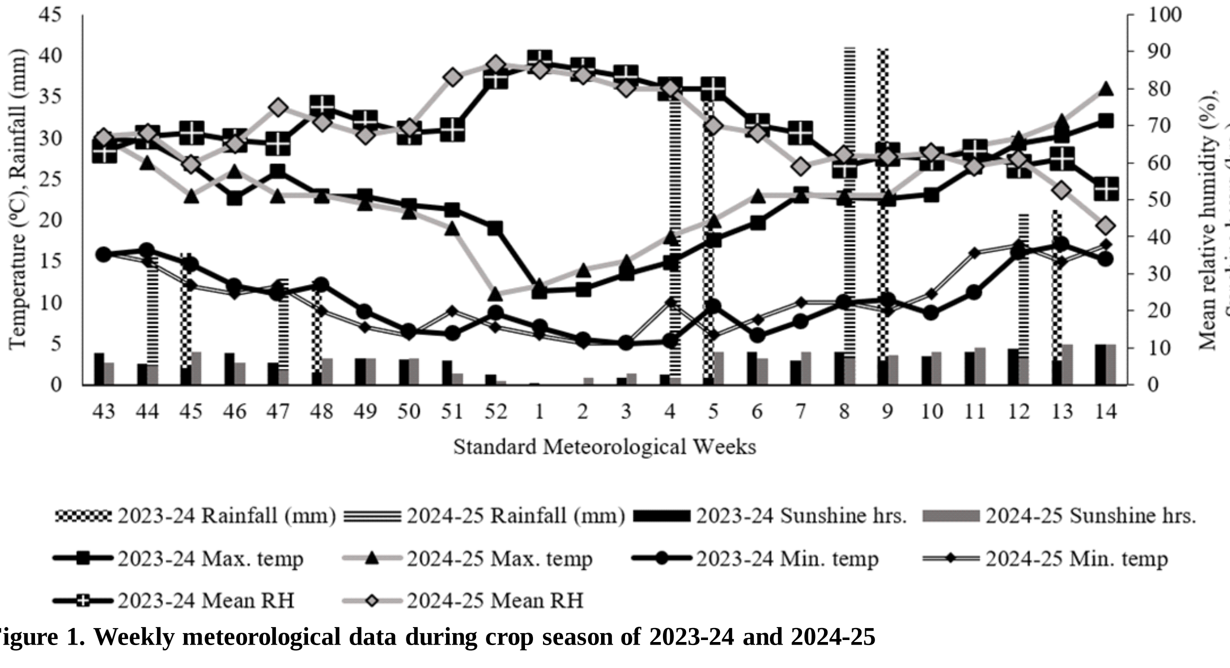

Figure 1. Weekly meteorological data during crop season of 2023-24 and 2024-25

The experiment was laid out in a split-plot design with three replications. The main plot treatments included three rice residue management methods involving oilseed rape seeding with Happy seeder, broadcast of oilseed rape seeds on rice straw, followed by copping of straw with mulcher (surface seeding-cum-mulching) and rice residue removed and oilseed rape seeding done in cultivated field (conventional method). The sub-plot treatments comprised three nitrogen levels, *viz*. 75% of the recommended dose of nitrogen (RDN) (75 kg N/ha), 100% RDN (100 kg N/ha), and 125% RDN (125 kg N/ha). Oilseed rape cv. GSC 7 was sown on was sown on 27 October, 2023 and 30 October, 2024 using 3.75 kg seed per hectare with methods as per main plot treatments. Each plot had a gross area of 20.5 m² and a net area of 12.4 m². A basal dose of 30 kg P/ha was applied at sowing through single superphosphate while nitrogen was applied through urea in two equal splits.

In Happy seeder treatment, oilseed rape was directly sown into standing and loose rice residues (a total residue load of 5.5 t/ha) using the PAU Happy seeder machine after uniform distribution of loose straw. Under surface seeding-cum-mulching method, oilseed rape seeds were broadcasted over the field immediately after combine harvesting, and then mulcher was used to cut and spread the straw. Entire phosphorus was applied as a basal dose at sowing and half of the nitrogen dose was applied as per treatment details, followed by uniform straw spreading with a straw cutter-cum-spreader. A light irrigation was applied immediately after sowing to ensure germination. In the conventional method, the field was prepared after complete residue removal, and oilseed rape sowing was performed using a tractor-drawn dual seed drill. In Happy seeder and conventional method plots, sowing was done in rows spaced 45 cm apart, and seedlings were thinned three weeks after sowing to maintain a uniform plant-to-plant spacing of 10 cm.

Weeds were counted species-wise using a 0.5 m × 0.5 m quadrat placed randomly at two spots in each plot at 30 days after sowing (DAS) before the manual weeding. Later, two hand weedings were performed, the first at 35 DAS and the second at 60 DAS. Weeds within each quadrat were cut at ground level and sorted by species. The collected samples were first sun-dried and then oven-dried at 60 ± 2 °C until constant weight was achieved. The dry weight of each weed species (weed biomass) was recorded separately and expressed as grams per square meter (g/m^2). Oilseed rape seed yield per plot was recorded at harvesting on 2 April 2024 and 3 April 2025 and was expressed in quintals per hectare after threshing, cleaning and drying. Lodging was recorded at harvest using a 0-9 scale, where 0 denoted no lodging and 9 indicated complete lodging. Net returns were calculated by deducting the variable cost of cultivation from the gross returns.

Data were analysed using CPCS-1 software to evaluate differences among treatments. Weed density and biomass values were subjected to square-root transformation before statistical analysis. Statistical analysis was carried out following the split-plot design as outlined by Gomez and Gomez (1984). Differences among treatment means were evaluated using the Fisher's Protected Least Significance Test (LSD) at the 5% probability level.

RESULTS AND DISCUSSION

Effect on weeds

Weed flora was dominated by broad-leaved weed species, particularly *Rumex dentatus*, *Medicago denticulata*, *Anagallis arvensis*, *Lepidium didymum* and *Alternanthera philoxeroides*. Weed density was significantly lower under surface seeding-cum-mulching method compared to Happy seeder and conventional method at 30 DAS (**Table 1**). This reduction was mainly due to complete soil coverage by residues, which limited light penetration and created a physical barrier to weed emergence. Similar findings were reported by Iqbal *et al.* (2020), where mulching suppressed weed growth by reducing light availability. The higher density of *A. philoxeroides* in surface seeding-cum-mulching plots was likely caused by stem fragmentation due to one operation of cutter-cum-spreader during straw cutting and its spreading, which promoted its regrowth from plant fragments. In contrast, Happy seeder method recorded significantly lower density of *A. philoxeroides* and other broad-leaved weed species as compared to conventional method, as surface-retained residues restricted weed emergence as reported earlier by Kaur *et al.* (2024) and Sraw *et al.* (2025) However, slightly higher weed density in the Happy seeder plots than in surface seeding-cum-mulching might be attributed to uneven residue distribution within crop rows. Overall, residue retention through both surface seeding-cum-mulching and Happy seeder effectively suppressed weed emergence compared with residue removal in conventional method. Choudhary and Bhagawati (2019) also found that groundnut haulm mulch at 4 t/ha in *toria* reduced the density of broad-leaved, grassy and sedge weeds by 49.1%, 20.5%, and 27.3%, respectively, over the no-mulch treatment.

A significant influence of nitrogen levels on weed density was observed (**Table 1**). Application of 75% RDN consistently resulted in lower weed density at 30 DAS compared with 100% and 125% RDN. Weed density was also significantly lower with the application of 100% RDN than 125% RDN. The reduction under lower nitrogen levels could be attributed to limited nutrient availability, which suppressed the growth and competitiveness of fast-growing weeds that respond vigorously to higher nitrogen supply. Shafiullah *et al.* (2018) similarly reported that increasing nitrogen application enhanced seed yield, biological yield and harvest index but also promoted higher weed infestation in rapeseed.

A significant interaction between rice residue management and nitrogen levels was observed for the density of *R. dentatus* (**Table 1**). Under Happy seeder, significantly lower weed density was recorded with 75% RDN than 100% RDN. In surface seeding-cum-mulching, 75% RDN was at par with 100% RDN, and 100% RDN was at par with 125% RDN, while 75% RDN recorded significantly lower density than 125% RDN. Under the conventional method, 75% RDN remained significantly lower than 100% and 125% RDN, and 100% RDN was significantly lower than 125% RDN. The influence of nitrogen was more pronounced in the conventional system, where exposed soil promoted faster weed establishment. Similarly, Sharma (2022) reported higher weed density under conventional tillage with flat-bed sowing and 100% N, while the lowest density occurred in permanent flat-beds with residue retention at 75% and 100% N. Among residue management practices, surface seeding-cum-mulching with 75% RDN recorded the lowest density of *R. dentatus*, and all other treatment combinations differed significantly. A similar pattern occurred in *M. denticulata* (**Table 1**), except that under Happy seeder, 100% RDN was at par with 125% RDN, and under surface seeding-cum-mulching, 100% RDN was significantly lower than 125% RDN. Surface seeding with 75% RDN again recorded the lowest density, with all remaining treatments differing significantly. For *A. arvensis*, trends matched those of *R. dentatus* (Table 1), except that surface seeding-cum-mulching with 75% RDN was at par with 125% RDN. Across residue management practices, surface seeding with 75%, 100%, and 125% RDN recorded statistically similar and significantly lower densities than other treatments and all other combinations differed significantly. For *A. philoxeroides*, the trend again resembled *R. dentatus* (**Table 1**), though under Happy seeder, 100% RDN was at par with 125% RDN, and under surface seeding-cum-mulching, 75% RDN recorded significantly lower density than 100% RDN. Among residue management practices, Happy seeder with 75% RDN recorded the lowest density, with conventional method under 75% RDN was at par with Happy seeder under 100% and 125% RDN.

Weed biomass of recorded weed species was significantly lower under surface seeding-cum-mulching method compared to Happy seeder and conventional method at 30 DAS (**Table 1**). However, this trend did not hold for *A. philoxeroides*, as Happy seeder method recorded the lowest biomass of this species due to its comparatively lower density under this treatment than under surface seeding-cum-mulching and the conventional method. The Happy seeder method also showed reduced weed biomass relative to conventional method, highlighting the effectiveness of residue retention in suppressing weed growth. This reduction may be attributed to uniform residue cover that restricted light penetration and acted as a physical barrier to weed emergence. Similar results were reported by Choudhary and Bhagawati (2019), who found that groundnut haulm mulch at 4 t/ha reduced weed dry biomass in *toria* (*Brassica campestris* L. *var. toria*) at 30 DAS compared to no-mulch plots.

A significant influence of nitrogen levels on weed biomass was also observed (**Table 1**). Application of 75% RDN consistently produced lower weed biomass at 30 DAS than 100% and 125% RDN. Application of 100% RDN also resulted in significantly lower weed biomass than 125% RDN for all recorded weed species, except for *A. arvensis* and *A. philoxeroides*, where 100% RDN remained at par with 125% RDN. The lower biomass under reduced nitrogen levels may be due to limited nutrient availability, which restricted weed growth and competitiveness. Conversely, higher nitrogen rates favoured weed proliferation, as many weed species utilize available nutrients more efficiently than crops (Blackshaw *et al.* 2003). Hu *et al.* (2017) similarly reported that nitrogen fertilization increased weed biomass and nitrogen uptake, though the response was less pronounced than in rapeseed.

There was a significant interaction between rice residue management practices and nitrogen levels on the weed biomass of *R. dentatus* at 30 DAS (**Table 1**). Under Happy seeder, 75% RDN recorded significantly lower biomass than 100% RDN, and 100% RDN was significantly lower than 125% RDN; similarly, 75% RDN remained significantly lower than 125% RDN. In surface seeding-cum-mulching, 75%

RDN was at par with 100% RDN, 100% RDN at par with 125% RDN, and 75% RDN at par with 125% RDN. In conventional method, 75% RDN recorded significantly lower biomass than 100% and 125% RDN, and 100% RDN was significantly lower than 125% RDN. Among residue management practices, surface seeding-cum-mulching with 75% RDN recorded the lowest *R.* biomass, while conventional 75% RDN was at par with Happy seeder 125% RDN.

A similar trend was observed in *M. denticulata* (**Table 1**), except that under surface seeding-cum-mulching, 75% RDN recorded significantly lower biomass than both 100% and 125% RDN. Surface seeding with 75% RDN recorded the lowest biomass of *M. denticulata*, while Happy seeder 75% RDN was at par with surface seeding 75% and 100% RDN. Conventional 75% RDN was at par with Happy seeder 125% RDN. *A. arvensis* also followed a trend

Table 1. Interactive effect of rice residue management and nitrogen level on weed density and biomass in oilseed rape at 30 DAS (pooled data of two years)

Rice residue management × Nitrogen levels treatment	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean
	Rumex dentatus (no./m^2)				*Rumex dentatus* (g/m^2)			
Happy seeder	4.70 (21)	5.25 (27)	5.70 (32)	5.23 (27)	1.73(2.08)	2.06(3.25)	2.39(4.75)	2.04(3.36)
Surface seeding-cum-mulching	2.88 (8)	3.12 (9)	3.23 (10)	3.08 (9)	1.42(1.01)	1.45(1.11)	1.44(1.18)	1.42(1.11)
Conventional method	6.76 (45)	8.45 (71)	9.30 (86)	8.17 (67)	2.41(4.88)	3.03(8.19)	3.65(12.36)	3.02(8.49)
Mean	4.79 (25)	5.61 (35)	6.07 (42)		1.84(2.67)	2.17(4.19)	2.47(6.10)	
LSD (p=0.05)	Rice residue management: 0.34; Nitrogen levels: 0.20; Nitrogen levels at same level of rice residue management: 0.34; Rice residue management at same and different level of nitrogen levels: 0.42				Rice residue management: 0.19; Nitrogen levels: 0.12 Nitrogen levels at same level of rice residue management: 0.21; Rice residue management at same and different level of nitrogen levels: 0.25			
	Medicago denticulata (no./m^2)				*Medicago denticulata* (g/m^2)			
Happy seeder	3.48(11)	3.93(15)	4.06(16)	3.83(14)	1.36(0.92)	1.77(2.22)	2.19(3.82)	1.76(2.33)
Surface seeding-cum-mulching	2.34(5)	2.59(6)	2.97(8)	2.61(6)	1.23(0.53)	1.42(1.09)	1.56(1.46)	1.41(1.04)
Conventional method	6.60(43)	7.48(55)	8.41(70)	7.48(56)	2.26(4.15)	2.99(8.00)	3.61(12.05)	2.95(8.07)
Mean	4.13(19)	4.66(25)	5.14(31)		1.62(1.88)	2.05(3.78)	2.46 (5.79)	
LSD (p=0.05)	Rice residue management: 0.26; Nitrogen levels: 0.17; Nitrogen levels at same level of rice residue management: 0.29; Rice residue management at same and different level of nitrogen levels: 0.33				Rice residue management: 0.17; Nitrogen levels: 0.09 Nitrogen levels at same level of rice residue management: 0.16; Rice residue management at same and different level of nitrogen levels: 0.20			
	Anagallis arvensis (no./m^2)				*Anagallis arvensis* (g/m^2)			
Happy seeder	1.83(3)	2.26(4)	2.68(6)	2.23 (4)	1.26(0.59)	1.40(0.96)	1.41(1.00)	1.35(0.85)
Surface seeding-cum-mulching	1.00(0)	1.00(0)	1.00(0)	1.00 (0)	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.00)
Conventional method	3.11(9)	3.65(12)	4.04(15)	3.60 (12)	1.74(2.05)	1.88(2.55)	1.94(2.77)	1.84(2.45)
Mean	1.98(4)	2.29(6)	2.56(7)		1.33(0.88)	1.42(1.16)	1.44(1.25)	
LSD (p=0.05)	Rice residue management: 0.31; Nitrogen levels: 0.13; Nitrogen levels at same level of rice residue management: 0.22; Rice residue management at same and different level of nitrogen levels: 0.33				Rice residue management: 0.07; Nitrogen levels: 0.04 Nitrogen levels at same level of rice residue management: 0.07; Rice residue management at same and different level of nitrogen levels: 0.08			
	Lepidium didymum (no./m^2)				*Lepidium didymum* (g/m^2)			
Happy seeder	2.65(6)	3.18(9)	3.70(13)	3.18(9)	1.10(0.21)	1.38(0.91)	1.79(2.21)	1.41(1.10)
Surface seeding-cum-mulching	1.14(0)	1.49(1)	2.00(3)	1.53(2)	1.16(0.34)	1.20(0.47)	1.38(0.91)	1.23(0.58)
Conventional method	6.58(43)	7.37(54)	7.87(61)	7.26(52)	2.30(4.30)	2.56(5.58)	2.84(7.12)	2.53(5.67)
Mean	3.44(16)	4.01(21)	4.52(26)		1.50(1.62)	1.68(2.32)	1.99(3.41)	
LSD (p=0.05)	Rice residue management: 0.39; Nitrogen levels: 0.18; Nitrogen levels × rice residue management: NS				Rice residue management: 0.11; Nitrogen levels: 0.08 Nitrogen levels at same level of rice residue management: 0.13; Rice residue management at same and different level of nitrogen levels: 0.15			
	Alternanthera philoxeroides (no./m^2)				*Alternanthera philoxeroides* (g/m^2)			
Happy seeder	1.00(0)	1.49(1)	1.72(2)	1.39(1)	1.04(0.09)	1.07(0.14)	1.08(0.19)	1.07(0.14)
Surface seeding-cum-mulching	3.52(12)	4.02(15)	3.91(14)	3.81(14)	1.94(2.79)	2.10(3.44)	2.18(3.76)	2.07(3.32)
Conventional method	1.67(2)	2.08(4)	2.56(6)	2.08(4)	1.09(0.20)	1.43(1.05)	1.44(1.08)	1.29(0.78)
Mean	2.06(5)	2.51(7)	2.71(7)		1.35(1.03)	1.52(1.54)	1.57(1.68)	
LSD (p=0.05)	Rice residue management: 0.24; Nitrogen levels: 0.15; Nitrogen levels at same level of rice residue management: 0.27; Rice residue management at same and different level of nitrogen levels: 0.31				Rice residue management: 0.07; Nitrogen levels: 0.06 Nitrogen levels at same level of rice residue management: 0.10; Rice residue management at same and different level of nitrogen levels: 0.10			

Weed data was subjected to square root transformation ($\sqrt{x+1}$) and means of original values were given in parentheses like *R. dentatus*, except that under Happy seeder, 100% RDN was at par with 125% RDN, and in conventional method, 100% RDN was at par with 125% RDN. Among residue management practices, surface seeding with 75%, 100% and 125% RDN recorded statistically similar and significantly lower biomass than all other treatment combinations. For *L. didymum*, the trend again resembled *R. dentatus*, except that under surface seeding-cum-mulching, 100% RDN recorded significantly lower biomass than 125% RDN, and 75% RDN also remained significantly lower than 125% RDN. Surface seeding with 75% RDN recorded the lowest biomass, while Happy seeder 75% RDN was at par with surface seeding 75% and 100% RDN, and Happy seeder 100% RDN was at par with surface seeding 125% RDN. In *A. philoxeroides*, the trend was like *R. dentatus*, except that under Happy seeder, 75% RDN was at par with 100% RDN and 100% RDN was at par with 125% RDN. In surface seeding-cum-mulching, 75% RDN recorded significantly lower biomass than both 100% and 125% RDN, while in conventional method, 100% RDN was at par with 125% RDN. Among residue management practices, the Happy seeder with 75% RDN recorded the lowest biomass and was at par with conventional 75% RDN, while conventional 75% RDN was at par with Happy seeder 100% and 125% RDN.

Effect on oilseed rape seed yield and net returns

Rice residue management practices and nitrogen application rates had a pronounced effect on the seed yield of oilseed rape (**Table 2**, **Figure 2**). Among rice residue management practices, sowing with happy seeder consistently outperformed surface seeding-cum-mulching as well as conventional method. The higher oilseed rape yield under the happy seeder treatment could be linked to improved crop growth conditions and better expression of yield-contributing traits. On pooled data of two years, happy seeder recorded a 10.6% higher oilseed rape seed yield than the conventional method and 24.2% more than surface seeding-cum-mulching. Similar yield advantages with residue retention have been noted earlier by Kadam *et al.* (2022) who documented a 7.1% rise in oilseed rape seed yield and an 8.3% increase in oilseed rape stover yield under residue-retained conditions. Improved moisture conservation, moderated soil temperature and reduced soil compaction likely contributed to better root development and enhanced productivity (Mondal *et al.* 2008). The conventional method also produced significantly higher oilseed rape yield than surface seeding-cum-mulching. The higher lodging of oilseed rape under surface seeding-cum-mulching (**Figure 2**) occurred because seeds were broadcasted on the soil surface during sowing, developed shallow root anchorage, resulting in weaker root-soil contact. Reduced root development under broadcasting method was also observed by Pandit *et al.* (2025). This vulnerability was further exacerbated by adverse weather, particularly rainfall during the reproductive stage (**Figure 1**). In contrast, Happy seeder and conventional sowing placed oilseed rape seeds at an optimal depth (4-5 cm), enabling stronger root development and greater lodging resistance and consequently significantly higher oilseed rape seed yield than surface seeding-cum-mulching method of sowing.

Table 2. Interactive effect of rice residue management and nitrogen levels on seed yield (t/ha) of oilseed rape (pooled analysis of two years)

Rice residue management × Nitrogen levels treatment	Seed yield (q/ha)			
	75% RDN	100% RDN	125% RDN	Mean
Happy seeder	2.05	2.40	2.55	2.33
Surface seeding-cum-mulching	180	1.97	1.88	1.89
Conventional method	1.82	2.17	2.34	2.11
Mean	1.89	2.18	2.26	

LSD (p=0.05) Rice residue management: 1.01; Nitrogen levels: 0.98; Nitrogen levels at same level of rice residue management: 1.70; Rice residue management at same and different level of nitrogen levels: 1.67

With respect to nitrogen, applying 125% of the recommended dose resulted in the highest seed yield, remaining statistically comparable to 100% RDN but superior to 75% RDN (**Table 2, Figure 2**). The improved nitrogen supply likely enhanced oilseed rape vegetative vigour, assimilate generation and their translocation to the reproductive structures, which collectively strengthened oilseed rape yield attributes such as siliquae formation and seed filling. Although higher nitrogen levels increased oilseed rape lodging due to taller plants and heavier canopies but lodging occurred late in the crop cycle. By this stage, the crop had already achieved superior growth and yield attributes under higher nitrogen supply, which minimized the impact of lodging on productivity. Consequently, higher nitrogen still resulted in greater oilseed rape seed yield than reduced nitrogen levels. On pooled analysis basis, oilseed rape seed yield increased by 19.4% with 125% RDN and by 15.4% with 100% RDN compared to 75% RDN. These findings align with those of Nayak *et al.* (2022), who reported notable improvements in seed yield with nitrogen applications of 120 and 150 kg/ha over 90 kg/ha.

A significant interaction was observed between rice-residue management practices and nitrogen levels on oilseed rape seed yield. Under Happy seeder method, the application of 100% RDN resulted in significantly higher oilseed rape seed yield than 75% RDN, while 100% RDN remained statistically at par with 125% RDN. However, application of 125% RDN recorded significantly higher yield than 75% RDN. Under surface seeding-cum-mulching method, application of 100% RDN produced significantly higher oilseed rape yield than 75% RDN, and 100% RDN remained at par with 125% RDN. In this method, 125% RDN also remained statistically at par with 75% RDN, which might be due to relatively higher lodging at 125% RDN that offset the benefits of additional nitrogen, while 100% RDN produced the highest yield by providing adequate nutrition without inducing lodging-related losses. In conventional method, application of 100% RDN recorded significantly higher yield than 75% RDN, while 100% RDN remained statistically at par with 125% RDN. Moreover, oilseed rape seed yield under 75% RDN remained significantly lower than 125% RDN.

Across residue management practices, the highest oilseed rape seed yield was observed under Happy seeder method with 125% RDN. The Happy seeder method of sowing with 75% RDN produced oilseed rape yield at par with surface seeding-cum-mulching method under 100% RDN and conventional method under 100% RDN. Surface seeding-cum-mulching method with 75% RDN also remained at par with conventional method under 75% RDN. The conventional method with 75% RDN also remained at par with surface seeding with 100% RDN and 125% RDN. Additionally, the seed yield produced under Happy seeder method with 100% RDN also remained statistically at par with conventional method with 125% RDN.

Rice residue management practices and nitrogen levels exerted a significant impact on the economics of oilseed rape. Among rice residue management methods, sowing with Happy seeder resulted in the highest net returns and it was higher than conventional and surface seeding-cum-mulching method. Amongst zero tillage-cum-residue retention, Happy seeder sowing method generated greater net returns than surface seeding-cum-mulching. The cost of oilseed rape cultivation was maximum under conventional method due to multiple field operations such as discing, harrowing, and planking, which substantially increased labour and fuel requirements. In contrast, sowing of oilseed rape with Happy seeder and surface seeding-cum-mulching method

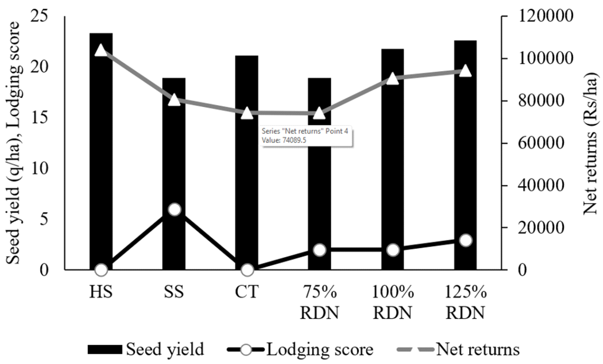

Figure 2. Effect of rice residue management and nitrogen levels on seed yield, lodging score and net returns of oilseed rape (pooled data of two years); HS, Happy seeder; SS, Surface seeding-cum-mulching; CT, Conventional method; 75% RDN, 75% of recommended dose of nitrogen; 100% RDN, 100% of recommended dose of nitrogen; 125% RDN, 125% of recommended dose of nitrogen

minimized production costs by integrating sowing and residue retention into a single operation and direct broadcasting with minimal field preparation, respectively. Net returns in surface seeding-cum-mulching remained lower than Happy seeder due to significantly reduced oilseed rape seed yield caused by lodging (**Figure 2**). Consequently, the combined advantages of effective weed suppression, reduced labour input, and superior oilseed rape yield made the Happy seeder method the most profitable and agronomically efficient rice residue management practice. Similar findings were reported by Jakhar *et al.* (2018) and Jat *et al.* (2024), who observed that zero-tillage practices with residue retention resulted in significantly greater net returns compared to conventional tillage.

It is concluded that the Happy seeder combined with optimal nitrogen provided the most sustainable weed management in oilseed rape with higher crop productivity under rice-oilseed rape rotation.

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