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Impact of black soldier fly frass in conjunction with urea on growth and yield of mustard (*Brassica juncea* L.) in Northern Telangana zone

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ABSTRACT

The present investigation entitled “Impact of black soldier fly frass in conjunction with urea on growth and yield of mustard (*Brassica juncea* L.) in Northern Telangana Zone” was conducted as a pot culture study under net-house conditions at the Regional Agricultural Research Station, Polasa, Jagtial, Professor Jayashankar Telangana State Agricultural University, Telangana, during rabi, 2024-25. The study was undertaken to evaluate the effect of black soldier fly larvae frass (BSFLF) applied in conjunction with urea on growth, yield attributes and yield of mustard. The experiment comprised of eight nitrogen management treatments with four replications, viz., T_1 : control (no nitrogen); T_2 : 100% recommended dose of nitrogen (RDN) through urea; T_3 : 50% RDN equivalent through BSFLF derived from poultry litter + 50% RDN through urea; T_4 : 75% RDN equivalent through BSFLF + 25% RDN through urea; T_5 : 100% RDN equivalent through BSFLF; T_6 : 50% RDN equivalent through aerobically composted poultry manure + 50% RDN through urea; T_7 : 75% RDN equivalent through aerobically composted poultry manure + 25% RDN through urea; and T_8 : 100% RDN equivalent through aerobically composted poultry manure. Integrated application of BSFLF and urea improved crop growth and yield attributes of mustard. Treatment T_3 recorded the highest plant height and number of branches plant-1 at harvest, along with higher SPAD values during the later growth stages. The highest number of siliquae plant-1 (80.0), seeds siliqua-1 (14.9), seed yield (16.5 g pot-1), stover yield (34.3 g pot-1) and harvest index (31.51%) were recorded with T_3 . The results indicated that integrated application of BSFLF and urea favourably influenced vegetative growth, yield attributes and yield of mustard under the experimental conditions.

Keywords: Black soldier fly frass, Urea, Mustard, Crop growth, Yield attributes, Seed yield

Introduction

Mustard (*Brassica juncea* L.) is an important oilseed crop belonging to the family Brassicaceae. Its seeds generally contain about 40-45 percent oil and 20-25 percent protein and are widely used for edible oil, condiments, pickles and other food preparations. Mustard oil is also used for cooking and in several industrial products, while the leaves are consumed as vegetables and used as green fodder (Anup Das *et al.*, 2018). In Telangana, mustard is cultivated mainly during the *rabi* season, particularly in the districts of Jagtial, Nizamabad, Nirmal and Kamareddy of the Northern Telangana Zone (Department of Agriculture, 2023). The crop therefore has importance in the agricultural production systems of the region.

Black soldier fly (*Hermetia illucens* L.) has gained considerable attention as a biological system for converting organic wastes into valuable products. During this process, black soldier fly larvae produce frass, which consists of larval excreta, exuviae and residual feed material. The resulting material contains plant nutrients and organic matter and has been identified as a potential organic fertilizer and plant growth-promoting material (Klammsteiner *et al.*, 2020; Schmitt and Devries, 2020; Gartling and Schulz, 2022) [1, 2, 3]. Several studies have reported beneficial effects of black soldier fly frass on plant growth and crop performance (Beesingamukama *et al.*, 2020; Barragán *et al.*, 2022). The nutrient composition and agronomic performance of black soldier fly frass can vary with the substrate used for insect rearing, making it necessary to evaluate its effect on individual crops under specific growing conditions. Although beneficial effects of frass have been reported in cereals and vegetable crops, information on its influence on growth, yield attributes and yield of oilseed crops such as mustard remains limited. Integration of black soldier fly frass with urea may provide both organic and readily available nitrogen and could favour crop growth and yield.

Therefore, the present investigation was undertaken to evaluate the effect of black soldier fly larvae frass applied in conjunction with urea on growth, yield attributes and yield of mustard under net-house conditions in the Northern Telangana Zone.

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Materials and methods

Experimental site

The pot culture experiment was carried out at shade net, Regional Agricultural Research Station (RARS) farm, Polasa, Jagtial. The shade net was located in the Northern Telangana zone and 284.17 me-

ters above mean sea level. Its geographical coordinates were 18° 50' 26" North latitude and 78° 56' 59" East longitude.

Initial soil properties

Experimental materials

Variety of the crop was Sitara sringar

- **Design:** Completely Randomized Design

Particulars	Values	Method of analysis
Sand (%)	64.20	Bouyoucos hydrometer method, (Piper, 1950)
Silt (%)	9.10	
Clay (%)	26.70	
Soil texture	Sandy Clay loam	
pH (1:2.5 soil: water)	6.88	Glass electrode pH meter (Jackson, 1973)
Electrical conductivity (dS m ⁻¹) (1:2.5 soil: water)	0.15	Conductivity meter (Jackson, 1973)
Organic carbon (%)	0.58	Chromic acid wet digestion method (Walkley and Black, 1934)
Available nitrogen (kg ha ⁻¹)	196.0	Alkaline KMnO ₄ method (Subbaiah and Asija, 1956)
Available P ₂ O ₅ (kg ha ⁻¹)	26.0	Olsen's method, Olsen <i>et al.</i> (1954)
Available K ₂ O (kg ha ⁻¹)	360.0	Flame photometer (Jackson, 1973)

Treatments: 8

- **Replications:** 4
- **Experimental units:** 32 pots

- **Soil:** 10 kg pot⁻¹

- **Crop:** Mustard

Treatments details of the experiment

T1	Absolute control (0 % Nitrogen)
T2	100% RDN through urea application
T3	Basal application of 50% RDN equivalent BSFLF derived from poultry litter + 50% RDN through urea
T4	Basal application of 75% RDN equivalent BSFLF derived from poultry litter + 25% RDN through urea
T5	Basal application of 100% RDN equivalent BSFLF derived from poultry litter
T6	Basal application of 50% RDN equivalent aerobically composted poultry manure + 50% RDN through urea
T7	Basal application of 75% RDN equivalent aerobically composted poultry manure + 25% RDN through urea
T8	Basal application of 100% RDN equivalent aerobically composted poultry manure

Pot culture experiment

Pot culture experiment was conducted in the net house of the Department of Soil Science and Agricultural Chemistry, Regional Agricultural Research Station, Polasa, Jagtial, Professor Jayashanker Telangana Agricultural University, Telangana. Glazed pots having 10 kg capacity were taken, labelled and filled with 10 kg of processed soil according to the treatments, the required quantities of BSFLF was incorporated and mixed thoroughly with the soil. The recommended dose of fertilizer (RDF) for mustard was (60-40-40 kg ha⁻¹ of N: P₂O₅: K₂O). Water was added to the soil samples to raise the moisture content to 50% of the field capacity. The moist samples were transferred in the pots and kept in the greenhouse.

Test crop

The crop chosen for the present experiment was Mustard (*Brassica juncea* L.). It was chosen as a test crop to see the effect of BSFLF equivalent and poultry manure equivalent as a source of nutrient. Variety of the crop used was Sitara sringar.

Sowing

The seeds of mustard were sown on 21 November 2024. Fourty seeds were sown in each pot and the upper layer was moistened with water to ensure proper germination. After germination of seeds, thinning

was done to maintain five plants per pot. The plants were maintained in the pot culture and care was taken to ensure proper growth.

Manures and fertilizers

Black soldier fly larval frass is incorporated into pots as per treatment required. A recommended dose of 60-40-40 kg ha⁻¹ of N:P₂O₅:K₂O as urea, single superphosphate and muriate of potash. Entire dose of nitrogen applied at basal and before flowering.

Irrigation

One irrigation was given immediately after planting for proper establishment. Depending on the soil moisture content, further irrigations were given at an interval of 5 - 10 days.

Weeding

Hand weeding was carried as per the required

Plant protection measures

Two sprays of insecticide viz. Dimethoate (Rogor 30 EC) was given using 625 ml of Dimethoate 30 EC in 200–250 L of clean water of hectare in succession at 15 days interval to avoid aphids infestation during experiment.

Harvesting

Harvesting was carried through manually after the crop showed physiological maturity. The crop was harvested, firstly by cutting down. Treatments wise plants were tied in bundles and left on threshing floor for drying. After drying, the harvested produce from each pot was threshed, dried, cleaned and collected in respective labelled bags as per the treatment.

OBSERVATIONS RECORDED

Five plants were taken from each pot and tagged in each replication and the mean value was calculated for crop growth and yield. Plant growth parameters

Plant height (cm)

The height of plants was measured from the surface of soil to the tip of plant at 15, 30, 45, 60 and at harvest after sowing with the help of a meter scale.

SPAD chlorophyll meter readings

The chlorophyll content of leaves from five tagged plants was estimated using SPAD chlorophyll meter at 15, 30, 45, 60 and at harvest.

Yield contributing characters and yield

Number of branches plant-1

Number of branches per plant of mustard were counted at days after sowing.

Number of siliquae plant-1 (cm)

Total number of siliquae of five plants were recorded in each pot and average number for each plant was calculated.

Number of filled seeds siliquae-1

The number of seeds per siliqua were counted from five pods of each mustard plant in a pot and averaged to express number of seeds per siliqua.

Test weight (g)

Handful of seeds were counted from each pot, and thousand seeds were counted randomly and weighed to be expressed in g.

Seed yield

After harvesting of crop, seeds were separated from the plant, kept in paper bags and dried in hot air oven at 60 + 2 °C till the weight became constant and seed yield (g pot-1) was computed.

Stover yield

Stover yield from each pots were sundried and weights were recorded in grams. It was expressed as mg pot-1

Harvest index (%)

The wholesome percentage of economic yield compared with biological yield (*i.e.*, above ground biomass) is called harvest index (Salisbury and Ross, 1986). It was calculated by using following formula.

$$\text{Harvest index (\%)} = \frac{\text{Economic yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}} \times 100$$

Statistical analysis

The crop data taken at different stages and at harvest were subjected to statistical analysis using completely randomized block design as illustrated by Panse *et al.* (1978) [4]. Statistical significance was tested by applying *F*-test at 0.05 level of probability and critical difference was calculated wherever treatments showed significant difference.

Results and discussion

3.1 Effect of black soldier fly frass and urea on plant height (cm)

The effect of different nitrogen management practices involving black soldier fly frass in conjunction with urea on plant height at different stages of crop growth is presented in Table

3.1. Plant height increased progressively from 15 DAS to harvest under all the nitrogen management treatments.

At 15 DAS, plant height varied from 5.03 to 5.76 cm. T₂ (100% RDN through urea application) recorded the highest plant height (5.76 cm), followed by T₄ (5.46 cm), T₇ (5.39 cm), T₃ (5.35 cm), T₆ (5.31 cm), T₅ (5.24 cm), T₈ (5.10 cm), and T₁ (5.03 cm). However, the differences among the treatments were not significant at this stage, indicating that the nitrogen management treatments had not yet produced a significant effect on plant height during the initial growth period.

At 30 DAS, plant height showed a significant response to nitrogen management. T₂ (100% RDN through urea application) recorded the highest plant height (16.4 cm), which was followed by T₅ (13.9 cm), T₄ (13.6 cm), T₃ and T₈ (13.3 cm each), T₇ (12.9 cm), and T₆ (12.8 cm). The control treatment, T₁ (no nitrogen), recorded the lowest plant height (10.2 cm). Thus, the application of nitrogen resulted in greater plant height compared with the control, with T₂ recording the highest value at this stage.

At 45 DAS, plant height increased considerably across all treatments and ranged from 54.1 to 70.7 cm. T₂ (100% RDN through urea application) continued to record the highest plant height (70.7 cm). Among the organic and integrated nitrogen treatments, T₅ (100% RDN through black soldier fly frass derived from poultry litter) recorded 65.0 cm, followed by T₄ (64.6 cm), T₈ (64.3 cm), T₃ (64.0 cm), T₇ (63.8 cm), and T₆ (61.9 cm). The lowest plant height was recorded in T₁ (54.1 cm).

At 60 DAS, application of 50% RDN equivalent through black soldier fly frass derived from poultry litter + 50% RDN through urea recorded the highest plant height (119 cm), followed by T₆ (50% RDN equivalent through aerobically composted poultry manure + 50% RDN through urea) at 115 cm and T₂ (100% RDN through urea application) at 114 cm. The remaining treatments recorded plant heights of 107 cm in T₄, 102 cm in T₇, 100 cm in T₅, and 98 cm in T₈, while T₁ recorded the lowest value (87 cm).

At harvest, plant height ranged from 98 to 149 cm. T₃ (50% RDN equivalent through black soldier fly frass derived from poultry litter + 50% RDN through urea) recorded the highest plant height (149 cm), followed by T₆ (141 cm), T₂ (129 cm), and T₄ (127 cm). Plant height under T₇, T₅ and T₈ was 117, 115 and 114 cm, respectively, whereas the minimum plant height was recorded in T₁ (98 cm).

The results therefore showed a distinct change in treatment response with crop advancement. T₂ (100% RDN through urea application) recorded the highest plant height during the early growth stages up to 45 DAS, whereas T₃ (50% RDN through black soldier fly frass derived from poultry litter + 50% RDN through urea) recorded the highest plant height from 60 DAS and at harvest. The control treatment consistently recorded the lowest plant height throughout the crop growth period.

Effect of black soldier fly frass and urea on number of branches per plant

The effect of different nitrogen management practices involving black soldier fly frass in conjunction with urea on the number of branches per plant is presented in Table 3.2. The number of branches per plant increased progressively with crop age under all treatments.

At 15 DAS, the number of branches per plant ranged from 3.09 to 3.50, with the maximum recorded in T₂ (100% RDN through urea application) (3.50) and the minimum in T₅ (100% RDN equivalent through black soldier fly frass derived from poultry litter) (3.09). The treatment differences were non-significant.

At 30 DAS, significant differences were observed among treatments. T₂ recorded the maximum number of branches (8.06), followed by T₅

(7.64), T_4 (7.54), T_3 (7.51), T_8 (7.48), T_7 (7.39), and T_6 (7.23), while T_1 (control, no nitrogen) recorded the minimum (5.69).

At 45 DAS, the number of branches ranged from 7.80 to 9.60. T_2 recorded the maximum (9.60), followed by T_6 (9.20), T_5 (8.80), T_4 (8.78), T_8 (8.71), T_3 (8.68), and T_7 (8.67), whereas T_1 recorded the minimum (7.80).

At 60 DAS, the highest number of branches was recorded in T_3 (50% RDN equivalent through black soldier fly frass derived from poultry litter + 50% RDN through urea) (12.0), followed by T_6 (11.0), T_2 (10.7), T_4 (10.1), T_5 (9.4), T_8 (9.3), T_7 (9.2), and T_1 (8.2).

At harvest, T_3 recorded the maximum number of branches per plant (13.2), followed by T_6 (13.0), T_2 (12.8), T_4 (12.4), T_7 (12.3), T_5 (12.2), T_8 (12.0), and T_1 (9.9).

Plant height and number of branches per plant showed a clear stage-dependent response to nitrogen management. During the early stages, T_2 (100% RDN through urea) recorded the highest values, particularly at 30 and 45 DAS, which may be attributed to the rapid availability of nitrogen from urea during active vegetative growth.

From 60 DAS onwards, T_3 (50% RDN equivalent through BSFLF derived from poultry litter + 50% RDN through urea) recorded the highest plant height and number of branches and maintained its superiority up to harvest. At harvest, T_3 recorded 149 cm plant height and 13.2 branches per plant compared with 129 cm and 12.8 branches per plant, respectively, under T_2 . This shift suggests that the integrated application of BSFLF and urea provided a more favourable nutrient supply pattern for sustained vegetative growth.

Among the treatments, application of 50% RDN through BSFLF + 50% RDN through urea recorded significantly higher crop growth compared with the other treatments. The combination of BSFLF and recommended dose of fertilizers appeared to provide well-balanced nutrient availability, facilitating improved crop growth (Geethanjali *et al.*, 2025). Moreover, the combined application of organic and inorganic sources could improve nutrient availability by providing both readily available and slowly released nutrient sources for plant growth (Du *et al.*, 2024).

The present findings therefore indicate that integrated application of BSFLF and urea was more effective in promoting plant height and branch formation than sole application of BSFLF. The results are broadly consistent with Beesigamukama *et al.*, (2020) [5], Adekiya *et al.*, (2019) [6], Liu *et al.*, (2024), Santos *et al.*, (2026) [7], Kumawat *et al.* (2014) [8] and Rosmiati *et al.*, (2017) [9].

Effect of black soldier fly frass and urea on SPAD values for leaf chlorophyll content

SPAD chlorophyll meter readings are an indirect measure of leaf chlorophyll content and photosynthetic efficiency. The data on SPAD chlorophyll meter readings at different crop stages as influenced impact of black soldier fly frass and urea are presented in Table 3.3.

The SPAD reading of mustard was significantly influenced by the different nitrogen management treatments at 30, 45 and 60 DAS, while the differences were non-significant at 15 DAS and at harvest. At 15 DAS, SPAD values ranged from 23.9 (T_7) to 27.7 (T_2), with no significant treatment effect. At 30 DAS, T_2 (100% RDN through urea) recorded the highest SPAD value (32.0), followed closely by T_3 (31.2) and T_5 (31.4), whereas T_1 recorded the lowest value (27.1).

At 45 DAS, T_3 (50% RDN through BSFL frass + 50% RDN through urea) recorded the highest SPAD value (32.8) and was significantly superior to the control (22.5). At 60 DAS, T_3 again recorded the highest value (33.1), indicating sustained leaf greenness under integrated application of BSFL frass and urea. At harvest, SPAD values ranged from 23.4 in T_1 to 28.0 in T_3 , but the treatment differences were non-significant.

The higher SPAD values under T_3 (50% RDN through BSFL frass + 50% RDN through urea) may be attributed to the complementary availability of nitrogen from organic and inorganic sources. Urea provides readily available N, while BSFL frass undergoes mineralization and gradually releases N and other nutrients, thereby maintaining N availability during crop growth (Beesigamukama *et al.*, 2021) [10].

The sustained SPAD values at 45 and 60 DAS (32.8 and 33.1) under T_3 may indicate better synchronization between N release and crop N demand. Integrated application of BSFL frass with mineral fertilizer has been reported to improve nutrient availability and crop N uptake (Anyega *et al.*, 2021) [11]. Since nitrogen is an essential component of chlorophyll and photosynthetic proteins, improved N nutrition can enhance leaf chlorophyll content and SPAD values. Similar improvement in chlorophyll status following BSFL frass application has been reported in maize (Beesigamukama *et al.*, 2020) [5], while integrated nutrient management with organic and inorganic fertilizers has also enhanced chlorophyll content in mustard (Kumawat *et al.*, 2014) [8].

Effect of black soldier fly frass and urea on yield attributes, seed and stover yield of mustard

Number of siliqua plant⁻¹

The number of siliqua plant⁻¹ is an important yield attribute that directly contributes to seed yield in mustard. The data pertaining to the number of siliqua plant⁻¹ as influenced by BSFLF and urea are presented in Table 3.4.

A critical examination of the data revealed that the treatments significantly influenced the number of siliqua plant⁻¹. The highest number of siliqua plant⁻¹ (80.0) was recorded with T_3 – 50% RDN through BSFLF + 50% RDN through urea, which was significantly superior over all other treatments. It was followed by T_6 (74.0), T_2 (67.8), T_4 (66.2), T_7 (61.0), T_5 (60.8) and T_8 (60.1), whereas the lowest value (50.6) was observed in control.

Number of filled seeds siliqua⁻¹

The number of seeds siliqua⁻¹ is an important component of mustard seed yield, as it determines the seed-bearing capacity of individual siliqua. The data pertaining to the number of seeds siliqua⁻¹ as influenced by BSFLF and urea are presented in Table 3.4.

The highest number of seeds siliqua⁻¹ (14.9) was recorded with T_3 – 50% RDN through BSFLF + 50% RDN through urea, followed by T_6 (13.1), T_2 (12.6), T_4 (11.3), T_5 (10.9), T_7 (10.6) and T_8 (10.2), while the lowest value (8.8) was recorded in T_1 – control (no nitrogen).

Test weight (1000 seed weight in g)

Data pertaining to test weight was presented in Table 3.4. Results revealed that the tested treatments did not show any significant difference in test weight. The test weight ranged from 5.0 to 6.2 g.

Seed yield (g pot⁻¹)

Seed yield represents the cumulative effect of crop growth, development of yield attributes, nutrient availability and the efficiency of nutrient utilization by the crop. The data pertaining to seed yield of mustard as influenced by different nitrogen sources are presented in Table 3.4.

A critical examination of the data revealed that the treatments significantly influenced seed yield of mustard. The seed yield ranged from 9.4 to 16.5 g pot⁻¹, with the highest seed yield of 16.5 g pot⁻¹ recorded in T_3 (50% RDN equivalent through BSFLF + 50% RDN through urea). T_3 recorded significantly higher seed yield than all the other treatments. The next highest seed yield was recorded with T_6 (50% RDN equivalent through aerobically composted poultry manure + 50% RDN through urea), which produced 15.7 g pot⁻¹, followed by T_2 (100% RDN through urea) with 13.2 g pot⁻¹. T_4 (75% RDN equivalent through BSFLF + 25% RDN through urea) recorded 12.7 g pot⁻¹, while T_7 (75% RDN equivalent through aerobically composted poultry manure + 25% RDN through urea) recorded 12.4 g pot⁻¹. The sole application of BSFLF (T_5) and aerobically composted poultry manure (T_8) resulted in seed yields of 12.1 and 11.8 g pot⁻¹, respectively. The lowest seed yield of 9.4 g pot⁻¹ was observed in the control (T_1).

The superiority of T_3 was also evident when compared with the control and the individual nutrient sources. T_3 increased seed yield by 75.5% over the control (T_1), indicating a substantial positive response of mustard to nitrogen application. Compared with 100% RDN

through urea alone (T_2), T_3 recorded a 25.0% higher seed yield. More importantly, compared with 100% RDN through BSFLF alone (T_5), the integrated treatment T_3 increased seed yield by 36.4%. Thus, the integration of BSFLF with urea resulted in greater seed yield than the sole application of either nitrogen source.

A similar trend was observed with aerobically composted poultry manure. The integrated treatment T_6 (50% RDN equivalent through aerobically composted poultry manure + 50% RDN through urea) recorded 15.4 g pot⁻¹, which was 30.5% higher than T_8 (100% RDN equivalent through aerobically composted poultry manure). T_6 also produced 27.3% higher seed yield than T_7 , indicating the advantage of combining an equal proportion of poultry manure-derived nitrogen with mineral nitrogen. However, T_3 produced 7.1% higher seed yield than T_6 , suggesting that the BSFLF–urea combination performed comparatively better than the corresponding aerobically composted poultry manure–urea combination.

The data further indicated that increasing the proportion of organic nitrogen beyond 50% did not result in a corresponding increase in seed yield. In the case of BSFLF, T_4 (75% BSFLF + 25% urea) produced 12.7 g pot⁻¹, which was 5.0% higher than sole BSFLF application (T_5) but 3.8% lower than sole urea application (T_2). Similarly, T_7 (75% poultry manure + 25% urea) recorded 12.4 g pot⁻¹, which was 5.1% higher than sole poultry manure application (T_8) but 6.1% lower than sole urea application (T_2). Overall, the results demonstrated that the integrated application of 50% RDN through BSFLF and 50% RDN through urea (T_3) was the most effective treatment for enhancing seed yield of mustard under the experimental conditions.

The superior seed yield obtained under T_3 appears to have resulted from the complementary contribution of BSFLF and urea to crop N nutrition. In the present study, T_3 not only increased seed yield but also improved the major yield components, particularly siliqua plant⁻¹, seeds siliqua⁻¹, and test weight. The concurrent improvement in these components suggests that the treatment supported both reproductive sink formation and subsequent seed filling, providing a stronger basis for the observed increase in final seed yield (Kumar *et al.*, 2022; Brahmabhatt *et al.*, 2024) [13, 12].

The response under T_3 can plausibly be related to the contrasting nutrient-release characteristics of the two N sources. The readily available N from urea could have supplied the crop during periods of high immediate demand, while the organic N fraction of BSFLF may have contributed nutrients progressively through microbial mineralization (Dzepe *et al.*, 2022) [14].

This would have reduced the dependence of the crop on a single source of N and potentially maintained N availability over a broader period of crop development. Such a pattern is particularly relevant to the present findings because the improvement in siliqua number, seeds siliqua⁻¹, and test weight indicates that the benefit of T_3 extended from reproductive development to seed maturation.

The processing of BSFLF may have further contributed to this response. Composting and anaerobic digestion can modify the chemical characteristics of frass and influence the conversion and subsequent release of organic nutrients, thereby affecting its agronomic effectiveness (Klammsteiner *et al.*, 2020; Watson *et al.*, 2021) [1, 2]. Thus, the performance of T_3 in this study may reflect not simply the combined application of organic and mineral N, but the interaction between the immediately available N supplied by urea and the nutrient-release characteristics of the processed BSFLF. This interpretation is consistent with the simultaneous improvement in yield attributes observed under T_3 and provides a plausible explanation for its superior seed yield.

Overall, the findings indicate that the T_3 combination created a more favourable N supply pattern for mustard than either source acting alone. The improved expression of siliqua formation, seed number, and seed weight under this treatment suggests that the combined N sources were effective in supporting the crop through the critical tran-

sition from reproductive development to seed filling. Therefore, the higher seed yield under T_3 may be interpreted as the cumulative outcome of improved N nutrition across these developmental stages, rather than merely a response to increased N availability.

The findings of the present study are in close agreement with those reported by Beesigamukama *et al.*, (2020) [5], Chavez *et al.*, (2023), Anyega *et al.*, (2021) [11], Kidd *et al.*, (2025) [15], Kullán *et al.*, (2026) [16], Boudabbous *et al.*, (2023) [17], Quilliam *et al.*, (2020) [18], Tanga *et al.* (2022) [19] and Ramiadantsoa *et al.*, (2026) [20].

Stover yield (g pot⁻¹)

The data on stover yield was presented in Table 3.4 and depicted in Fig. 3.1. The treatments significantly influenced stover yield, which ranged from 26.6 to 34.3 g pot⁻¹. The highest stover yield of 34.3 g pot⁻¹ was recorded with T_3 (basal application of 50% RDN equivalent BSFLF derived from poultry litter + 50% RDN through urea), followed by T_6 (50% RDN equivalent aerobically composted poultry manure + 50% RDN through urea) with 32.5 g pot⁻¹. T_2 (100% RDN through urea) recorded a stover yield of 31.4 g pot⁻¹, followed by T_4 (75% RDN equivalent BSFLF + 25% RDN through urea) with 30.4 g pot⁻¹. The treatments T_7 , T_5 and T_8 recorded stover yields of 29.8, 29.5 and 29.3 g pot⁻¹, respectively. The lowest stover yield of 26.6 g pot⁻¹ was recorded in the control (T_1).

The higher stover yield under T_3 may be attributed to the integrated supply of nutrients from organic and inorganic N sources, which could have promoted better root activity and nutrient uptake. The resulting improvement in nutrient acquisition may have enhanced vegetative growth and dry matter accumulation, leading to greater stover production. Similar improvements in stover yield under integrated nutrient management have been reported by Pal *et al.*, (2018), Rundal *et al.*, (2013) [21], Bhati *et al.*, (2014) [22] and Lepcha *et al.*, (2015) [23].

Harvest index (%)

Harvest index is an important indicator of reproductive efficiency and represents the proportion of economic yield relative to total biological yield. The data on harvest index are presented in Table 3.4. The harvest index values ranged from 25.02 to 31.51% under different treatments.

The highest harvest index of 31.51 per cent was recorded with T_3 (50% RDN through BSFLF + 50% RDN through urea), followed by T_6 (31.15%). The control treatment (T_1) recorded the lowest harvest index of 25.02 per cent. T_2 recorded a harvest index of 28.55 per cent, while T_4 , T_7 , T_5 and T_8 recorded 28.35, 28.33, 27.96 and 27.58 per cent, respectively.

The higher harvest index under integrated nutrient management may be attributed to improved nutrient availability, enhanced dry matter production and better partitioning of assimilates towards reproductive organs. Similar improvement in biomass partitioning and harvest index with increasing nitrogen supply in Indian mustard was reported by Kumar *et al.* (2001) [24]. Improved productivity and nutrient uptake under integrated nutrient management in mustard were also reported by Singh *et al.* (2011) [25] and Singh *et al.* (2014) [26].

Conclusions

Integrated application of 50% RDN equivalent through BSFLF derived from poultry litter + 50% RDN through urea (T_3) improved growth, yield attributes and productivity of mustard, recording the highest seed yield and stover yield.

With the present investigation, it could be concluded that integrated application of 50% RDN equivalent through BSFLF derived from poultry litter + 50% RDN through urea was effective in improving growth, yield, nutrient uptake and agronomic nitrogen use efficiency of mustard under the conditions of the present experiment in the Northern Telangana Zone. However, since the study was conducted under pot culture conditions, further field-level validation across seasons and soil types is required before wider recommendation.

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Table 3.1. Effect of black soldier fly frass in conjunction with urea on plant height (cm) of mustard

Treatments	15 DAS	30 DAS	45 DAS	60 DAS	At harvest
T ₁ - Control (No Nitrogen)	5.03	10.2	54.1	87	98
T ₂ -100% RDN through urea application	5.76	16.4	70.7	114	129
T ₃ - Basal application of 50% RDN equivalent BSFLF derived from poultry litter + 50% RDN through urea	5.35	13.3	64.0	119	149
T ₄ - Basal application of 75% RDN equivalent BSFLF derived from poultry litter + 25 % RDN through urea	5.46	13.6	64.6	107	127
T ₅ - Basal application of 100% RDN equivalent BSFLF derived from poultry litter	5.24	13.9	65.0	100	115
T ₆ - Basal application of 50% RDN equivalent aerobically composted poultry manure + 50% RDN through urea	5.31	12.8	61.9	115	141
T ₇ - Basal application of 75% RDN equivalent aerobically composted poultry manure + 25% RDN through urea	5.39	12.9	63.8	102	117
T ₈ - Basal application of 100% RDN equivalent aerobically composted poultry manure	5.10	13.3	64.3	98	114
SEm _±	0.17	0.42	2.66	3.18	2.60
CD (<i>p</i> = 0.05)	NS	1.24	7.79	9.28	7.61
CV (%)	6.50	6.40	8.40	6.05	4.21

Table 3.2. Effect of black soldier fly frass in conjunction with urea on number of branches per plant of mustard

Treatments	15 DAS	30 DAS	45 DAS	60 DAS	At harvest
T ₁ - Control (No Nitrogen)	3.21	5.69	7.80	8.2	9.9
T ₂ -100% RDN through urea application	3.50	8.06	9.60	10.7	12.8
T ₃ - Basal application of 50% RDN equivalent BSFLF derived from poultry litter + 50% RDN through urea	3.46	7.51	8.68	12.0	13.2
T ₄ - Basal application of 75 % RDN equivalent BSFLF derived from poultry litter + 25 % RDN through urea	3.36	7.54	8.78	10.1	12.4
T ₅ - Basal application of 100% RDN equivalent BSFLF derived from poultry litter	3.09	7.64	8.80	9.4	12.2
T ₆ - Basal application of 50% RDN equivalent aerobically composted poultry manure + 50% RDN through urea	3.31	7.23	9.20	11.0	13.0
T ₇ - Basal application of 75% RDN equivalent aerobically composted poultry manure + 25% RDN through urea	3.30	7.39	8.67	9.2	12.3
T ₈ - Basal application of 100% RDN equivalent aerobically composted poultry manure	3.41	7.48	8.71	9.3	12.0
SEm _±	0.09	0.23	0.23	0.22	0.27
CD (<i>p</i> = 0.05)	NS	0.82	0.67	0.64	0.79
CV (%)	5.82	6.37	5.28	4.46	4.43

Table 3.3. Effect of black soldier fly frass in conjunction with urea on SPAD reading of mustard

Treatments	15 DAS	30DAS	45 DAS	60 DAS	At harvest
T ₁ - Control (No Nitrogen)	25.4	27.1	22.5	23.5	23.4
T ₂ -100% RDN through urea application	27.7	32.0	27.0	29.7	25.6
T ₃ - Basal application of 50% RDN equivalent BSFLF derived from poultry litter + 50% RDN through urea	24.9	31.2	32.8	33.1	28.0
T ₄ - Basal application of 75 % RDN equivalent BSFLF derived from poultry litter + 25% RDN through urea	24.4	30.9	28.6	30.2	26.0
T ₅ - Basal application of 100% RDN equivalent BSFLF derived from poultry litter	25.8	31.4	28.0	28.8	24.6

(continued on next page)

Treatments	15 DAS	30DAS	45 DAS	60 DAS	At harvest
T ₆ - Basal application of 50% RDN equivalent aerobically composted poultry manure + 50% RDN through urea	25.1	30.4	30.1	30.1	26.8
T ₇ - Basal application of 75% RDN equivalent aerobically composted poultry manure + 25% RDN through urea	23.9	31.0	28.9	29.6	25.9
T ₈ - Basal application of 100% RDN equivalent aerobically composted poultry manure	24.6	30.8	26.8	27.0	25.2
SEm _±	0.76	0.69	1.09	0.89	0.87
CD (<i>p</i> = 0.05)	NS	2.01	3.18	2.60	NS
CV (%)	6.07	4.51	7.78	6.14	6.80

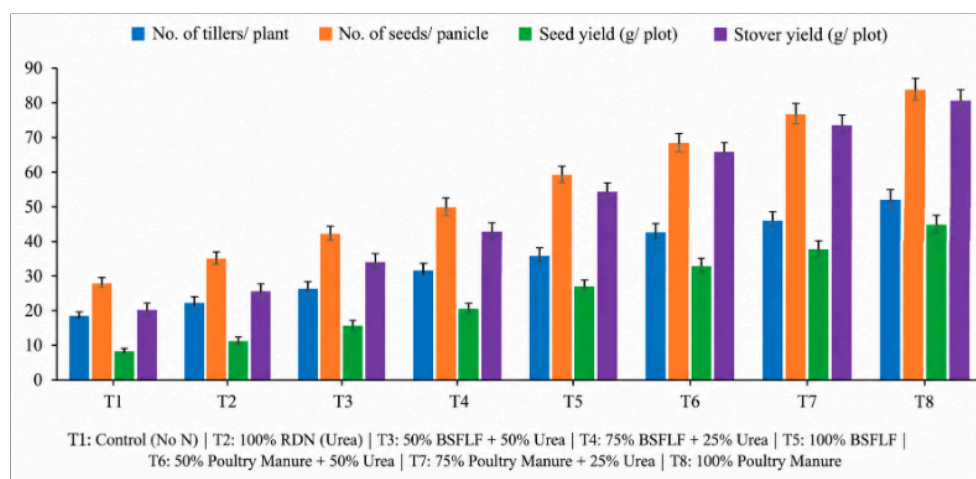


Fig. 3.4. Effect of black soldier fly frass in conjunction with urea on yield attributes and yield of mustard

Table 3.4. Effect of black soldier fly frass in conjunction with urea on yield attributes and yield of mustard

Treatments	No. of siliqua plant-1	No. of seeds siliqua-1	Seed yield (g pot-1)	Stover yield (g pot-1)	Test weight (g)	Harvest index (%)
T ₁ - Control (No Nitrogen)	50.6	8.8	9.4	26.6	5.0	25.02
T ₂ -100% RDN through urea application	67.8	12.6	13.2	31.4	5.6	28.55
T ₃ - Basal application of 50% RDN equivalent BSFLF derived from poultry litter + 50% RDN through urea	80.0	14.9	16.5	34.3	5.9	31.51
T ₄ - Basal application of 75 % RDN equivalent BSFLF derived from poultry litter + 25 % RDN through urea	66.2	11.3	12.7	30.4	5.4	28.35
T ₅ - Basal application of 100% RDN equivalent BSFLF derived from poultry litter	60.8	10.9	12.1	29.5	5.2	27.96
T ₆ - Basal application of 50% RDN equivalent aerobically composted poultry manure + 50% RDN through urea	74.0	13.1	15.7	32.5	5.7	31.15
T ₇ - Basal application of 75% RDN equivalent aerobically composted poultry manure + 25% RDN through urea	61.0	10.6	12.4	29.8	5.3	28.33
T ₈ - Basal application of 100% RDN equivalent aerobically composted poultry manure	60.1	10.2	11.8	29.3	5.1	27.58
SEm _±	0.87	0.36	0.34	0.78	0.19	0.89
CD (<i>p</i> = 0.05)	2.54	1.0	0.99	2.29	NS	2.60
CV (%)	2.67	6.26	5.28	5.16	7.07	6.24

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