Research Article

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Leather Meal Biocompost Enhances Mustard Yield by Improving Crop Nitrogen Utilization under Soil Salinity Stress

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ABSTRACT
Soil salinity is a major concern for agricultural productivity and requires sustainable approaches to enhance crop production. Organic fertilizers serve as innovative solution for enhancing crop yields and mitigating adverse effects of salinity. This field study investigated the effects of organic fertilizers, viz. vermicompost (VC) and leather meal biocompost (LMBC) on the growth, yield, and oil content of mustard (*Brassica juncea* L., cv. Mustard Raya), applied alone or in combination with inorganic nitrogen (N) fertilizer on a saline soil. The treatments arranged in a randomized complete block design with three replications, included 100% inorganic N, 100% VC, 100% LMBC, 50% VC + 50% inorganic N, and 50% LMBC + 50% inorganic N. Phosphorus and potassium fertilizers were applied to all experimental units as basal dose. The results revealed that the application of 100% inorganic N and 50% LMBC + 50% inorganic N significantly ($P < 0.05$) enhanced number of seeds per siliqua (21.1 and 19.7), 1000-seed-weight (7.1 g and 6.7 g), seed yield (2301 kg ha^{-1} and 2171 kg ha^{-1}), stover yield (5891 kg ha^{-1} and 5639 kg ha^{-1}) and oil content (39.3% and 38.1%), respectively. The maximum plant height (210.6 cm) and number of siliqua per plant (587.6) were recorded with 100% inorganic N treatment only. Based on the results of this study, it is concluded that leather meal biocompost, when co-applied with 50% inorganic N, proved to be a sustainable strategy in enhancing mustard yield and oil content under saline conditions, while reducing N fertilizer input up to 50%. This reduced N input contributes to more sustainable nutrient management on saline soils, with potential long-term soil health benefits.

Keywords: Saline soil, organic fertilizers, vermicompost, leather meal, mustard.

INTRODUCTION

Soil salinity is a widespread environmental stress that negatively affects crop production and rapidly degrades soil, particularly in arid and semi-arid regions (Meena et al., 2024; Rashmi et al., 2024; Jamro et al., 2025). According to a report by the FAO (2024), approximately 1.4 billion hectares of global land is affected by soil salinity. More specifically, arid and semi-arid regions are more commonly affected as salinity is spread over approximately 20% of irrigated lands in these regions (Zia-ul-hassan & Arshad, 2006) with some areas affected by heavy metal contamination (Bux et al. 2022, 2023).

Mustard (*Brassica juncea* L.) is an important oilseed crop of the world, cultivated over a large area due to its oil, which is used for different purposes, particularly as edible oil (Sahu et al., 2020). However, the global production of edible oil is figured out to be around 223 million tonnes, and the consumption is at the record of 250 million tonnes (Meijaard et al., 2024). This gap indicates that it is highly necessary to increase oil production to meet the needs of the rising population by enhancing the yields of oilseed crops, including mustard (Meena et al., 2022). However, the rising levels of salinity due to different natural and human activities have resulted in significant declines in mustard seed yield, and it is reported that salinity stress may decrease mustard seed yield by 40%. Moreover, salinity stress also leads to a reduced rate of photosynthesis, and increased oxidative stress, resulting in significant crop yield losses (Jamali & Zia-ul-hassan, 2025).

Alongside stressful conditions, nutrient deficiencies contribute equally to stunted plant growth and

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development. Pakistani soils have variable nutrient deficiencies, with nitrogen (N) (Maqsood et al., 2022), phosphorus (Memon et al., 2024; Arain et al., 2025), and zinc deficiency most commonly observed (Jamali et al., 2025; Tunio et al., 2025). However, in the case of potassium, its rapid mining is a major concern (Zia-ul-hassan et al., 2014). For nutrient deficit soils, it is commonly advised that site-specific fertilizer management should be adopted (Mari et al., 2025; Ujjan et al., 2025).

Among the essential nutrients, N is of prime importance for mustard growth and oil production as seed yield and oil content are directly related to seed N content (Mathur et al., 2022). Nitrogen deficiency in saline soils is widespread due to poor soil fertility (Meena et al., 2024), and this deficiency can adversely affect mustard production due to the fact that N is required by plants in highest amount of all nutrients (Meena et al., 2024).

Soil N deficiency can be addressed by supplying crops with external N sources. Organic manures, including farmyard manure, vermicompost (Bhanwaria et al., 2022), bonemeal (Talpur et al., 2025), biochar (Ahmed et al., 2024), and leather meal (Pati & Chaudhary, 2015; Sundar, 2023) are rich sources of nutrients, including N and play significant roles in improving soil health and mitigating the adverse effects of salinity stress (Bhanwaria et al., 2022; Rashmi et al., 2024). Organic fertilizers from various sources, whether raw or processed can be effectively utilized in plant nutrition. Studies have shown that the application of different types of organic fertilizers proved beneficial in enhancing crop productivity by effectively providing nutrients in balanced proportion under both normal and stressed conditions (Pati & Chaudhary, 2015; Shujrah et al., 2024; Talpur et al., 2025; Zia-ul-hassan et al., 2025).

Considering the high costs, low efficiency, and environmental concerns of inorganic N fertilizers, a field experiment was conducted to evaluate the effects of vermicompost and leather meal applied alone and in combination with inorganic N fertilizer on the growth, yield and oil content of mustard in saline conditions.

MATERIALS AND METHODS

The experiment was launched at the experimental field of Integrated Waterlogging & Salinity Program, Sindh Water and Agriculture Transformation Project (SWAT), Agriculture Research Sindh, Tandojam.

Experiment Details

The study was arranged in a randomized complete block design with three repeats. The treatments were vermicompost (VC) and leather meal biocompost (LMBC) applied alone or in combination with inorganic N fertilizer, viz. 100% inorganic N, 100% VC, 100% LMBC, 50% VC + 50% inorganic N, and 50% LMBC + 50% inorganic N. Pure seeds of mustard variety Khanpur Raya were sown in 20 m^2 (5.0 m x 4.0 m) sub-plots at a seed rate of 4.0 kg ha^{-1}. Phosphorus and potassium fertilizers were applied at 90-60 kg P-K ha^{-1} to all experimental units, through single superphosphate and potassium sulphate, respectively, as basal dose. VC and LMBC were applied and thoroughly mixed with soil before sowing at the rate of 2.5 tonnes ha^{-1} and 1.0 ton ha^{-1}, respectively. While inorganic N fertilizer was applied using ammonium sulphate in three equal splits. The crop was irrigated six times throughout the season. The crop was regularly monitored for necessary management practices, which were implemented as per crop's requirements following established protocols. At maturity, five randomly selected plants were harvested to record various agronomic observations. Oil content in mustard seeds was determined using Soxhlet apparatus (Folch et al., 1957). The organic fertilizers were prepared locally, at Agriculture Research Sindh, Tandojam. Vermicompost was prepared using raw farmyard manure with small quantities of azolla and duckweed in a heap method (Edwards & Arancon, 2004). Leather meal biocompost was prepared using leather sourced from slaughterhouses and leather industries, poultry manure, and sugarcane molasses in a 3:6:1 ratio. The scraps of untanned leather were mechanically shredded followed by their addition in the composting heap. Bacterial inoculations of *Bacillus, Pseudomonas, and Azotobacter* spp. were added to the composting heap as starters at 100 g per 100 kg of composting material to accelerate the decomposition of leather, owing to its decreased rate of mineralization. The nutrient composition of VC and LMBC analyzed following Ryan et al. (2001) is illustrated in Figure 1.

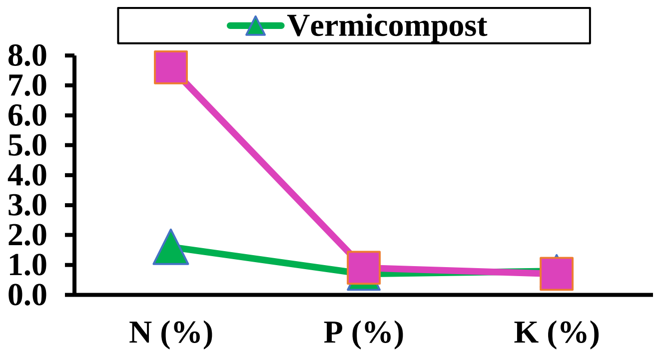

Figure 1. Nutrient composition of vermicompost and leather meal biocompost.

The N content of VC was 1.6%, and this value is typically observed in VCs prepared using farmyard manure. While the N content of LMBC was observed to be 7.6% owing to the presence of protein-rich leather residues which provide substantial organic N during the composting process. Soil samples were collected from the experimental area prior to any fertilizer applications for the analysis of various soil properties (Ryan et al., 2001). The analyses showed that the experimental soil was silt loam in texture, extremely saline (3.2 dS m^{-1}), strongly alkaline in reaction (pH 8.5), low in organic matter (0.57%), N (0.046%), and P (3.3 mg kg^{-1}), and marginal in K (81 mg kg^{-1}).

Statistical Analysis The collected data was initially processed using Microsoft Excel (2023). The data were tested for normality using the Shapiro–Wilk test, followed by analysis of variance using Statistix ver. 8.1. The treatment means were separated for significant differences using the LSD test at alpha 0.05 ($P < 0.05$).

RESULTS

The data pertaining to the growth traits of mustard, including plant height, number of siliqua per plant, number of seeds per siliqua, and 1000-seed-weight as affected by the application of VC and LMBC alone or in combination with inorganic N fertilizer on saline soils is summarized in Table 1.

Table 1. Growth traits of mustards as influenced by vermicompost and leather meal biocompost applied alone or in conjunction with inorganic N fertilizer

Treatments	**Plant height (cm)**	**Number of siliqua plant^{-1}**	**Number of seeds siliqua^{-1}**	**1000-seed-weight (g)**
100% inorganic N	210.6 a	587.6 a	21.1 a	7.1 a
100% VC	173.1 c	451.6 d	14.6 c	4.7 d
100% LMBC	175.1 c	461.0 d	15.4 c	5.0 c
50% VC + 50% inorganic N	196.5 b	525.7 c	17.5 b	6.0 b
50% LMBC + 50% inorganic N	199.8 b	564.3 b	19.7 a	6.7 a
$LSD_{0.05}$	5.9149	14.576	1.7579	0.439

Means followed by same letters in a column do not significantly differ at alpha 0.05 ($P < 0.05$)

The growth traits of mustard exhibited significant variations in response to different fertilizer treatments. Regarding plant height, a marked increase over all the treatments was recorded with full dose of inorganic N fertilizer. Plant height was significantly better under the co-application of 50% VC with 50% inorganic N and 50% LMBC with 50% inorganic N, than their sole applications, however, these co-applications were statistically at par with each other. The sole application of VC and LMBC did not significantly increase plant height of mustard and were found statistically at par with each other.

Number of siliqua per plant were recorded highest with full dose of inorganic N, followed by the co-application of 50% LMBC with 50 inorganic N. The co-application of 50% VC with 50% inorganic N underperformed when compared to the co-application of LMBC with inorganic N, but outperformed the sole applications of VC and LMBC which were non-significantly different from each other.

The maximum number of seeds per siliqua were recorded with full dose of inorganic N which was non-significantly different from the co-application of 50% LMBC with 50% inorganic N followed by the co-application of 50% VC with 50% inorganic N. The sole applications of VC and LMBC did not significantly increase the number of seeds per siliqua, and were found statistically at par with each other.

The maximum 1000-seed-weight was recorded with full dose of inorganic N which was non-significantly different from the co-application of 50% LMBC with 50% inorganic N followed by the co-application of 50% VC with 50% inorganic N. Between the sole applications of VC and LMBC, the application of LMBC differed significantly from VC which recorded the minimum 1000-seed-weight.

The data regarding the yield traits of mustard, such as seed and stover yield as affected by the application of VC and LMBC alone or in combination with inorganic N fertilizer on saline soils is illustrated in Figure 2. It was found that both the yield parameters were substantially improved in response to VC and LMBC and their co-application with inorganic N fertilizer.

The maximum seed yield was observed in the case of full dose of inorganic N which was non-significantly different from the co-application of 50% LMBC with 50% inorganic N, followed by the co-application of 50% VC with 50% inorganic N. In the case of sole applications of VC and LMBC, the application of LMBC differed significantly from VC which acquired the minimum seed yield.

A similar trend was observed for stover yield, where the maximum yield was obtained from the full dose of inorganic N, followed by the co-application of 50% LMBC with 50% inorganic N, and then 50% VC with 50% inorganic N. Between the sole organic treatments, LMBC again outperformed VC, which resulted in the lowest stover yield.

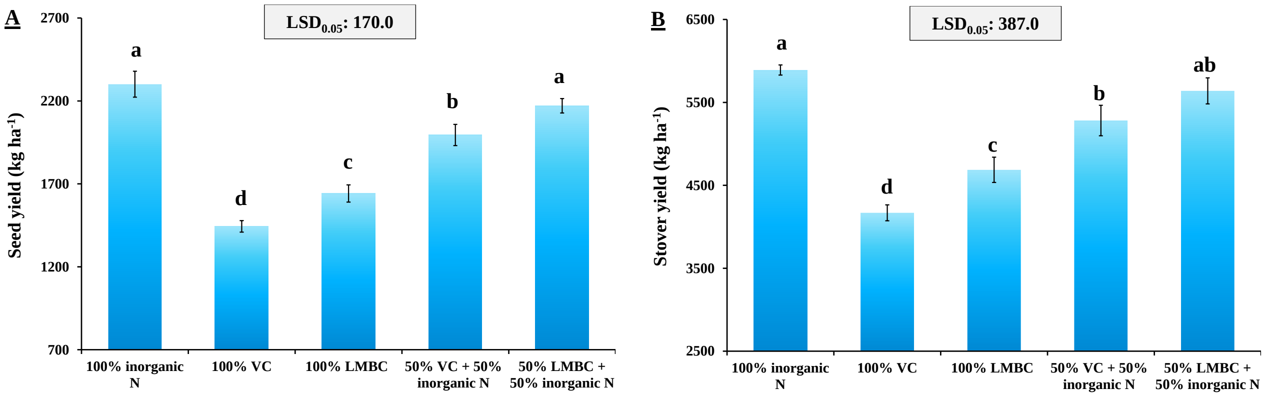

Figure 2. Seed yield (A) and stover yield (B) of mustard as influenced by vermicompost and leather meal biocompost applied alone or in conjunction with inorganic N fertilizer

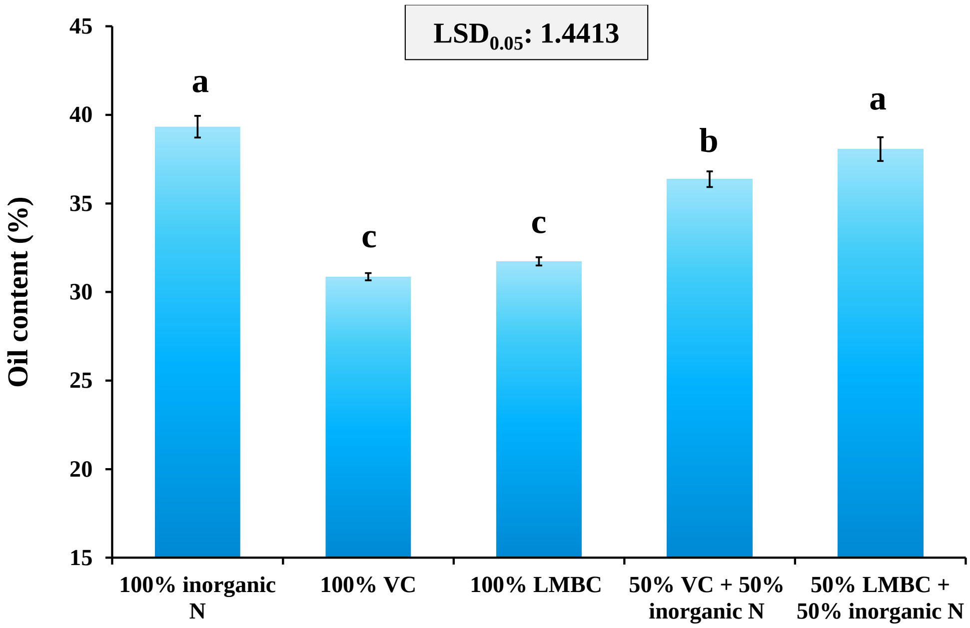

Figure 3. Oil content of mustard as influenced by vermicompost and leather meal biocompost applied alone or in conjunction with inorganic N fertilizer

Data related to oil content of mustard seeds as affected by the application of VC and LMBC alone or in combination with inorganic N fertilizer is depicted in Figure 3. Mustard oil content was found significantly different across VC and LMBC and their co-application with inorganic N fertilizer. Maximum oil content was determined in the case of full dose of inorganic N fertilizer which was non-significantly different from the co-application of 50% LMBC with 50% inorganic N followed by the co-application of 50% VC with 50% inorganic N. The minimum oil content was determined in the case of sole application of VC which was statistically at par with the sole applications of LMBC.

DISCUSSION

Soil salinity stress is a major challenge for plant growth, as high salt concentrations can reduce plant nutrients and water absorption, damage cellular structures, and reduce crop growth and yields, threatening food security (Jamali & Zia-ul-hassan, 2025). Nitrogen is an essential element for plant growth and development (Maqsood et al., 2022), however, salinity can reduce N uptake, limit the activity of key enzymes, and cause N deficiency. (Meena et al., 2022, 2024). Organic fertilizers play vital roles in improving saline soils by increasing soil N content and promoting beneficial microbial activity. Studies show that combining organic fertilizers with inorganic N fertilizers can significantly improve crop yield and N utilization in salt-affected soils (Xiao et al., 2025).

The present study was conducted on saline soil, evaluating the effects of sole and combined applications of vermicompost and leather meal biocompost with inorganic N fertilizers on mustard crop. The findings demonstrated that plant height and number of siliqua per plant were acquired maximum with full dose of inorganic N fertilizer which proved significantly better in comparison to sole and co-applications of VC and LMBC with inorganic N (Table 1). Number of seeds per siliqua, 1000-seed-weight, seed and stover yield, and oil content were observed maximum with full dose of inorganic N, which was statistically at par with 50% LMBC co-applied with 50% inorganic N, showcasing the key role of LMBC when combined with half dose of inorganic N fertilizer in enhancing mustard yield and oil content (Table 1; Figure 2 & 3). The results indicated that LMBC performed better than VC due to its higher N content and faster mineralization, which improved crop N utilization under salinity stress, leading to enhanced yield and oil accumulation.

To the best of our knowledge, the literature has remained silent for the relevant studies on leather meal based organic plant nutrition. However, there are some comparable studies conducted in the past, such as employing purified protein hydrolysate as N supplement sourced from leather shavings on soybean production. Interestingly, this formulated leather-based fertilizer achieved better seed yield over chemical fertilizers (Pati & Chaudhary, 2015). In another research, animal fleshing produced from leather industry were converted into leather meal and applied to ladyfinger plants, suggesting that protein based solid wastes may be processed into organic fertilizers for sustainable crop production (Sundar, 2023). Although only a few comparable studies have been conducted using leather-based organic fertilizers, they report some key implications that leather meal based organic plant nutrition results in improved crop yields and soil health. These mechanisms include rapid mineralization due to its low carbon to nitrogen ratio and stimulation of microbial N transformation. Moreover, its higher N content due its high protein and amino acids content also aids in soil fertility enhancement (Pati & Chaudhary, 2015; Sundar, 2023).

The present study aligns with those existing in the literature that organic fertilization supports plant growth under salinity stress. It is due to the fact that these organic amendments reduce Na+ toxicity, increase microbial biomass, improve osmotic adjustment, and counteract the negative effects of salts in the rhizosphere (Meena et al., 2024; Rashmi et al., 2024). Several studies show the beneficial impacts of combined application of N-enriched organic fertilizers with inorganic N fertilizers on a diverse range of crop species under both favorable and unfavorable environmental conditions. Previous studies reported that combined organic and inorganic nutrient management is one of the most effective approaches for managing saline soils, the increasing oilseed crop yields, and improving soil health. This sustainable approach not only reduces the adverse effects of salinity but also improve N-use-efficiency, soil fertility and economic returns for farmers (Irin and Biswas, 2023; Li et al, 2025). The evidence supports a move toward more sustainable, organic-based plant nutrition management on salt affected soils to provide for long term productivity and resilience of oilseed cropping systems.

Oilseed crops, including mustard, are among the highly sensitive crops to salinity. From previous studies, it has been observed that saline soils that have a higher sodium absorption ratio are capable of reducing up to 50 percent of mustard seed yield (Meena et al., 2024). However, a combination of organic and inorganic sources of N such as 50% recommended dose of N plus vermicompost can ensure maximum seed yield (Meena et al., 2022). The use of green manures and crop residues further enhances soil fertility and reduce the dependency on chemical N fertilizers for subsequent crops (Irin & Biswas, 2023). These organic amendments present the most comprehensive benefits for saline soils, which are better than chemical amendments to improve both the soil quality and crop productivity (Li et al, 2025). Moreover, in another study, seed yield increased 1.6-fold in response to the combined application of 50 percent recommended chemical fertilizer with 5 t ha^{-1} vermicompost, when compared to the control, hence proving the effectiveness of integrated nutrient management. Poultry manure and cow dung, combined with chemical fertilizers, also helped improve the yield but the vermicompost was found to be the most effective organic source for maximum yield (Reza et al., 2022). It is evident from these findings that integrated use of organic manures with chemical fertilizers not only improves growth, yield, and oil content, however improves economic returns which is indication of their agronomic and economic benefits for mustard cultivation. This study focused mainly on enhancing mustard yield and oil content under the salinity stress. While deeper evaluations, including residual effects of the applied organic amendments on soil properties and economic returns were not the objectives of this study. Therefore, it should be considered in future research to fully understand the long-term benefits of integrated application of organic and inorganic fertilizers on crop growth, soil health, and environment.

CONCLUSION

The application of 100% inorganic N and 50% leather meal biocompost with 50% inorganic N fertilizer significantly enhanced the number of seeds per siliqua, 1000-seed-weight, seed yield, and oil content of mustard. This concludes that leather meal biocompost combined with 50% inorganic N can be a sustainable strategy for enhancing mustard yield and oil content under saline conditions, while saving up to 50% inorganic N fertilizer input. Beyond yield benefits, this approach focuses on resource-efficient agriculture, supporting crop production under salt-affected soils. The future research is warranted to validate these results, alongside investigating the long-term effects of LMBC and its integration with inorganic fertilizers.

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CONFLICT OF INTERESTS

All authors declare no conflicts of interests.

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