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Improving soil physical properties and yield of mustard greens through vermicompost and nitrogen application

I Made Sukerta*[1)], Ni Putu Eka Pratiwi[1)], Komang D. Ananda[1)], Ramdhoani Ramdhoani[1)], Lily M. Limantara*[2)]

[1)] Universitas Mahasaraswati Denpasar, Faculty of Agriculture and Business, Agro-technology Study Program, Jalan Kamboja No. 11A Denpasar 80233, Indonesia

[2)] University of Brawijaya, Faculty of Engineering, Department of Water Resources, Jl. MT Haryono No. 167, Malang 65145, Indonesia

* Corresponding author

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Abstract: This study evaluated the effects of combined vermicompost and nitrogen fertilisation on soil physical properties and the yield of mustard greens (*Brassica juncea* L.) cultivated under coastal dryland conditions in Jungutbatu Village, Nusa Lembongan, Bali, Indonesia. The experiment was conducted during a single growing season using a factorial randomised block design with six vermicompost rates (0–25 Mg·ha^{-1}) and four nitrogen levels (0–138 kg N·ha^{-1}), each replicated three times. Vermicompost was incorporated into the soil prior to planting, while nitrogen was applied as urea during crop growth. Plant growth parameters, biomass yield, and selected soil physical and chemical properties were assessed. The combined application of vermicompost and nitrogen significantly affected the plant height, leaf area index, and total biomass yield. The highest fresh (238.52 Mg·ha^{-1}) and oven-dried biomass (12.53 Mg·ha^{-1}) were obtained with 25 Mg·ha^{-1} vermicompost combined with 138 kg N·ha^{-1}. Improvements in soil porosity and permeability, and reductions in bulk density, were also observed as accompanied by increases in soil organic carbon and total nitrogen. Regression analysis indicated predominantly linear responses of biomass yield to increasing fertiliser doses, suggesting additive rather than synergistic effects under the conditions of this study. These findings demonstrate the short-term potential of integrated organic and inorganic fertilisation to improve mustard productivity and soil physical quality in nutrient-poor coastal drylands. However, further multi-season and multi-site studies are required to evaluate the long-term soil effects, environmental risks, and the economic feasibility of high vermicompost application rates.

Keywords: crop productivity, dryland agriculture, nutrient management, organic fertiliser, soil fertility

INTRODUCTION

Green mustard (*Brassica juncea* L.) is an important horticultural crop in Indonesia, widely consumed due to its high nutritional value, including vitamins A, B, and C. Despite its adaptability to both lowland and highland areas, the production of green mustard often fails to meet the increasing market demand driven by population growth and greater awareness of healthy diets (Budiasih *et al.*, 2018; Pradita and Janicka, 2025). The rising demand is particularly evident in urban and tourism-driven regions, where fresh leafy vegetables are required year-round. However, production remains constrained by environmental limitations and suboptimal soil management practices (Kumar *et al.*, 2021; Winberg, Smith and Ekroos, 2023).

One of the major challenges in expanding mustard cultivation into dryland areas is the inherently low soil fertility, particularly with respect to nitrogen and organic matter, coupled with limited water availability. These constraints reduce nutrient retention and water availability, thereby limiting plant growth, nutrient uptake, and crop productivity (Musei *et al.*, 2024; Vadez *et al*., 2024). Advances in cultivation techniques have been developed to improve crop productivity, with fertilisation being one of the most effective strategies (Dey *et al*., 2024). Nitrogen, a key macronutrient, plays a central role in leaf development, protein synthesis, and chlorophyll formation (Huizil *et al*., 2024). Nitrogen deficiency leads to chlorosis, stunted growth, and reduced yield (Loki, 2025), while excessive application may result in weak, overly succulent plants that are prone to pests and lodging.

Integrating nitrogen with organic amendments, such as vermicompost, has been increasingly recognised as an effective strategy to enhance soil fertility, improve crop growth, increase nutrient use efficiency, and promote sustainable agricultural practices (Manzoor *et al*., 2024; Sande *et al*., 2024). Vermicompost, also known locally as kascing, is a biologically active organic fertiliser produced by the decomposition of organic matter through earthworm activity (Manzoor *et al*., 2024). It contains a balanced supply of macro- and micronutrients, humic substances, and beneficial microorganisms. Its low C/N ratio promotes faster mineralisation and higher microbial activity, leading to improved nutrient availability for plants (Mkhonza, Buthelezi-Dube and Muchaonyerwa, 2020). Previous studies have demonstrated that vermicompost significantly improves soil physical quality by reducing bulk density, increasing soil porosity, and enhancing soil water retention capacity, thereby improving water availability in the root zone under drought-prone conditions (Castellini *et al*., 2024; Hermawan *et al*., 2024). In addition, vermicompost has been reported to stimulate nutrient availability, microbial activity, and root–mycorrhizal interactions, which contribute to improved early plant growth and root development (Xue and Bakker, 2022). Recent studies have shown that vermicompost application to *Brassica juncea* and related leafy vegetables significantly improves soil nitrogen, phosphorus, and potassium availability, enhances soil structure, and increases yield in sandy and nutrient-poor soils (Manzoor *et al*., 2024; Raksun *et al*., 2024).

Jungutbatu Village, Nusa Lembongan, represents a coastal dryland agroecosystem where vegetable production faces acute soil fertility constraints. As the area develops into a tourism hub, local demand for fresh vegetables, particularly mustard greens, continues to rise. However, the region's sandy soils have low organic carbon and nitrogen content, which limit crop productivity. Previous research has focused mainly on single interventions such as nitrogen fertilisation, while integrated nutrient management approaches (e.g., combining organic and inorganic sources) have been shown to produce greater improvements in growth and yield of mustard (*Brassica juncea* L.) and nutrient dynamics in soil (Sreerenjiny and Debbarma, 2022; Venkatesh *et al*., 2023) or plant spacing (Kwiatkowski, Haliniarz and Harasim, 2020), but there has been limited investigation into the combined effects of organic and inorganic fertilisation under these unique coastal dryland conditions. This gap is consistent with findings from Kumar *et al*. (2021) and Malav, Salvi and Jat (2024), who emphasised that integrated nutrient management remains underutilised in coastal and dryland vegetable production systems. This gap in knowledge is significant for two reasons. Coastal drylands present both physical and chemical soil constraints that require integrated management strategies. Moreover, the additive and interactive effects of vermicompost and nitrogen application remain insufficiently quantified, particularly in relation to soil physical properties such as porosity, bulk density, and permeability, which are critical indicators of soil structural quality under water-limited conditions (Castellini *et al*., 2024; Hermawan *et al*., 2024). Therefore, this study aims to evaluate the interactive effects of vermicompost and nitrogen on the growth, yield, and soil physical properties in mustard green cultivation under dryland conditions in Nusa Lembongan.

The specific objectives are:

1) to determine the influence of varying doses of vermicompost and nitrogen on plant growth parameters (plant height, number of leaves, and leaf area index);
2) to assess their combined effects on biomass yield (fresh and oven-dried);
3) to analyse improvements in soil physical and chemical properties in response to integrated fertilisation.

The working hypothesis is that higher doses of vermicompost, when combined with an adequate nitrogen supply, will produce additive effects, resulting in improved growth, increased biomass yield, and enhanced soil physical properties compared to the application of either input alone. By addressing these objectives, the study is expected to contribute scientific evidence for integrated nutrient management in coastal dryland agroecosystems. This approach aligns with sustainable agriculture goals and may support local food availability in tourism-influenced regions. Furthermore, the findings could provide a reference for managing nutrient-poor soils in other tropical dryland environments, while recognising site-specific and temporal limitations.

Advancements in cultivation practices are continuously being developed to overcome the challenges of low soil fertility and climate stress in tropical agricultural systems. Recent systematic reviews highlight the role of integrated nutrient management (INM), wich combines vermicompost and inorganic fertilisers, in improving soil properties and crop productivity across diverse environments (Sande *et al*., 2024). Among essential macronutrients, nitrogen (N) plays a pivotal role in leaf development, protein synthesis, and photosynthetic activity (Huizil *et al*., 2024). Nitrogen deficiency typically leads to leaf chlorosis and stunted plant growth, whereas excessive application can result in overly lush vegetative growth and weak plant structures (Tang, 2025).

Organic matter, derived from the decomposition of plant and animal residues such as green manure, compost, and animal waste, significantly contributes to soil fertility. It enhances microbial activity, increases cation exchange capacity, reduces soil compaction and cracking, improves drainage and aeration, buffers soil pH, enhances moisture retention, and reduces erosion (Ghosh *et al*., 2020).

Vermicompost (kascing), which is the result of organic matter decomposition by earthworms, has been recognised as a superior organic fertiliser. Its benefits include high microbial activity, rapid nutrient mineralisation, and a well-balanced profile of macro- and micronutrients (Manzoor *et al*., 2024). Vermicompost also improves soil porosity, permeability, and moisture retention (Mkhonza, Buthelezi-Dube and Muchaonyerwa, 2020), and it reduces bulk density while enhancing soil water availability and structural stability, which are essential for plant growth under water-limited conditions (Castellini *et al*., 2024; Hermawan *et al*., 2024). In addition, vermicompost promotes nutrient availability, microbial activity, and root–microbial interactions that support improved root development (Xue and Bakker, 2022).

Research conducted in tropical dryland environments shows that integrating vermicompost with nitrogen fertilisers produces synergistic effects, improving both physiological traits and yield components of mustard greens (Sreerenjiny and Debbarma, 2022; Ejraei, Ghehsareh and Hodaji, 2023). However, studies investigating this combined application in coastal dryland regions, such as Nusa Lembongan, remain limited. This knowledge gap is particularly important, considering the inherently low soil moisture, organic carbon, and nitrogen contents (Nackley *et al.*, 2024).

Recent findings highlight the importance of integrated nutrient management (INM), particularly the combined use of organic amendments and mineral fertilisers, in improving crop productivity, nutrient-use efficiency, and soil health (Manzoor *et al.*, 2024; Sande *et al.*, 2024). Thus, understanding the effects of combined organic and inorganic fertilisation on soil physical properties and crop yield is essential, especially for smallholder farming systems in marginal and fragile agroecosystems.

Mustard greens (*Brassica juncea* L.) are smooth, non-hairy, annual leafy vegetables that do not produce fruit (Raksun *et al.*, 2024). They possess a root system consisting of taproots and lateral roots that are elliptical in shape and spread in all directions up to a depth of 30–50 cm. The stem is segmented, very short, and almost invisible. Taxonomically, mustard greens belong to the Cruciferae family (Ilhamiyah *et al.*, 2019).

Historically, mustard greens originated from East Asia and China, then spread to Taiwan and the Philippines. The crop was introduced to Indonesia in the 19th century along with other subtropical vegetables, especially from the cabbage group, through cross-regional trade. This plant can be cultivated in both lowland and highland areas, but 100–500 m a.s.l. is considered optimal.

Mustard greens grow best in organic-rich soils with a pH of 6–7 (Anwar, Trisnawaty and Hasanuddin, 2024). Several varieties are heat-tolerant and can thrive at temperatures ranging from 27°C to 31°C. The market demand is particularly high among noodle and meatball vendors, and Chinese restaurants due to the plant's culinary appeal.

The crop is typically harvested between 40–50 days after planting, depending on physical indicators such as yellowing of the lower leaves, which marks physiological maturity (Kumar *et al.*, 2022).

MATERIALS AND METHODS

STUDY AREA AND EXPERIMENTAL SITE

The field experiment was conducted from December 9, 2022, to January 30, 2023, in Jungutbatu Village, Nusa Lembongan, Klungkung Regency, Bali, Indonesia (08°14'17"–08°50'57" S; 115°05'02"–115°15'09" E). The area represents a coastal dryland agroecosystem characterised by sandy soils, low organic matter content, and limited nutrient availability. The site is located approximately 5 m a.s.l. The region experiences a tropical monsoon climate with average temperatures ranging from 27°C to 31°C during the experimental period. Rainfall was relatively low and irregular; therefore, supplemental irrigation was applied manually to prevent severe water stress.

SOIL CHARACTERISTICS

Composite soil samples were collected from the 0–20 cm depth prior to treatment application for initial characterisation. The soil texture was classified as sandy loam. Initial soil chemical properties indicated very low fertility, with total nitrogen at 0.09%, organic carbon at 0.55%, available phosphorus at 28.45 mg·kg^{-1}, and exchangeable potassium of 22.6 meq·(100 g)$^{-1}$.

VERMICOMPOST CHARACTERISTICS

The vermicompost was locally produced from organic agricultural residues through earthworm activity (*Eisenia foetida*). The material was fully matured, as indicated by its dark colour, crumb structure, and earthy odour. It was applied as a soil amendment without further processing.

EXPERIMENTAL DESIGN AND TREATMENTS

The experiment employed a factorial randomised block design with two factors: nitrogen fertilisation and vermicompost application. Nitrogen was applied at four levels: 0, 46, 92, and 138 kg N·ha^{-1} using urea fertiliser (46 kg N·ha^{-1} corresponded to approximately 100 kg urea·ha^{-1}, equivalent to 14.4 g urea per plot). Vermicompost was applied at six rates: 0, 5, 10, 15, 20, and 25 Mg·ha^{-1}. Each treatment combination was replicated three times, resulting in 72 experimental plots. Each experimental plot had an area of 1.44 m^2 (1.2 × 1.2 m). Vermicompost was incorporated evenly into the topsoil (0–20 cm) one week before planting, whereas nitrogen fertiliser was applied in two equal splits, with half applied at planting and the remainder 21 days after planting (DAP).

CROP MANAGEMENT

Green mustard (*Brassica juncea* L.) of the Toksakan variety was sown directly in the field. Irrigation, weeding, and pest control were applied uniformly across all plots. Irrigation was provided manually using hoses to maintain adequate soil moisture. Pest and disease management employed Derosal fungicide and Baycarb insecticide as needed.

PLANT GROWTH AND YIELD MEASUREMENTS

Plant height, number of leaves, and leaf area index (*LAI*) were recorded at 14, 21, 28, and 35 DAP. Plant height was measured from the soil surface to the highest leaf tip, and leaves were counted manually. At harvest, plants were collected to determine fresh biomass yield per plot and per hectare. Samples were oven-dried at 70°C until a constant weight to obtain oven-dried biomass yield, expressed per hectare.

SOIL PHYSICAL AND CHEMICAL ANALYSES

Soil samples were collected seven days after fertilisation and at harvest. Bulk density was determined using the core method; soil porosity was calculated from bulk density. Soil permeability was measured using standard laboratory procedures. Organic carbon was analysed using the Walkley–Black method, and total nitrogen by the Kjeldahl method. Leaf nitrogen content was also measured to assess plant nitrogen uptake.

STATISTICAL ANALYSIS

Data were subjected to analysis of variance (ANOVA) based on a factorial randomised block design at a significance level of 5%. Significant differences among treatment means were separated using Duncan's multiple range test at $p < 0.05$. Regression analyses were performed to assess the relationships between nitrogen and vermicompost application rates and fresh and oven-dried biomass yields. All statistical analyses were conducted using IBM SPSS Statistics version 25 software.

METHODOLOGICAL LIMITATIONS

This study was conducted at a single location during one growing season; therefore, results represent short-term responses under specific coastal dryland conditions. Further multi-season and multi-location research is recommended to confirm long-term effects.

RESULTS AND DISCUSSION

ANALYSIS OF VARIANCE OF GROWTH, YIELD, AND SOIL PROPERTIES

The statistical analysis revealed a highly significant interaction between nitrogen and vermicompost treatments for multiple growth and yield parameters of mustard greens (*Brassica juncea* L.). These included plant height at 21 and 28 days after planting (DAP), leaf area index (*LAI*) at 14, 21, and 35 DAP, and both fresh and oven-dried biomass per hectare (Tab. 1). The consistent statistical significance across multiple growth stages indicates that the combined application of organic and inorganic fertilisers produced additive and interactive effects throughout the crop cycle, rather than being limited to specific growth stages. Similar interaction patterns were reported by Kumar *et al.* (2021), who found that integrated nutrient application enhanced canopy development and biomass accumulation in sandy loam soils.

RELATIONSHIP BETWEEN NITROGEN AND VERMICOMPOST APPLICATION RATES AND BIOMASS YIELD

Regression analysis was applied to describe the linear response trends between fertiliser doses and biomass yield, rather than to determine optimal fertiliser rates. The relationship between vermicompost application rate and fresh biomass yield (Eqs. 1–4) at each nitrogen level followed a linear pattern:

$$Y_{\mathrm{FM}} = 64.124 + 2.287\mathrm{N}_0; R^2 = 0.991; r = 0.995** \quad (1)$$

$$Y_{\mathrm{FM}} = 95.821 + 2.725\mathrm{N}_1; R^2 = 0.965; r = 0.982** \quad (2)$$

$$Y_{\mathrm{FM}} = 108.557 + 4.447\mathrm{N}_2; R^2 = 0.985; r = 0.992** \quad (3)$$

$$Y_{\mathrm{FM}} = 147.482 + 3.352\mathrm{N}_3; R^2 = 0.976; r = 0.988** \quad (4)$$

where: Y_{FM} = fresh biomass yield (Mg·ha^{-1}), N_0, N_1, N_2, and N_3 = nitrogen application rates of 0, 46, 92, and 138 kg N·ha^{-1}, respectively, R^2 = coefficient of determination, r = correlation coefficient.

Table 1. Significance of application of the N doses and vermicompost (K) effect and interaction of (N × K) on mustard greens growth and yield variables

Variable	Significance in treatment		
	N	K	N × K
Plant height at age:			
– 14 DAP	**	**	ns
– 21 DAP	**	**	**
– 28 DAP	**	**	**
Number of leaves at age:			
– 14 DAP	**	**	ns
– 21 DAP	**	**	ns
– 28 DAP	**	**	ns
– 35 DAP	**	**	ns
Leaf area index at age:			
– 14 DAP	**	**	**
– 21 DAP	**	**	**
– 28 DAP	**	**	ns
– 35 DAP	**	**	**
Leaf stalk length	**	**	ns
Total fresh biomass yield (g per plot)	**	**	**
Total fresh biomass yield (Mg·ha^{-1})	**	**	**
Total oven-dry biomass yield (g per plot)	**	**	**
Total oven-dry biomass yield (Mg·ha^{-1})	**	**	**
Leaf N content	**	**	**
Total soil nitrogen (%)			
– 7 DAF	ns	**	ns
– Harvest time	**	**	ns
Soil organic carbon (%)			
– 7 DAF	ns	**	ns
– Harvest time	**	**	**
Ground water level			
– 7 DAF	**	**	ns
– Harvest time	**	**	**
Soil volume weight			
– 7 DAF	**	**	**
– Harvest time	**	**	**
Soil permeability			
– 7 DAF	**	**	**
– Harvest time	**	**	**
Total soil pore space			
– 7 DAF	**	**	**
– Harvest time	**	**	**

Explanations: ** = very significant effect ($p < 0.01$), * = significant effect ($p < 0.05$), ns = no significant effect ($p \geq 0.05$), DAP = days after planting, DAF = days after fertilisation.
Source: own study.

Similarly, the relationship between vermicompost application rate and oven-dry biomass yield (Eqs. 5–8) at each nitrogen level was linear:

$$Y_{\mathrm{DM}} = 3.716 + 0.115\mathrm{N}_0; R^2 = 0.964; r = 0.983** \quad (5)$$

$$Y_{\mathrm{DM}} = 4.801 + 0.115\mathrm{N}_1; R^2 = 0.893; r = 0.945** \quad (6)$$

$$Y_{\mathrm{DM}} = 5.067 + 0.172\mathrm{N}_2; R^2 = 0.940; r = 0.969** \quad (7)$$

$$Y_{\mathrm{DM}} = 5.521 + 0.254\mathrm{N}_3; R^2 = 0.963; r = 0.981** \quad (8)$$

where: Y_{DM} = oven-dry biomass yield (Mg·ha^{-1}).

Likewise, the relationship between nitrogen application rate and oven-dry biomass yield at each vermicompost level was linear (Eqs. 9–14):

$$Y_{\mathrm{DM}} = 3.765 + 0.01643\mathrm{K}_0; R^2 = 0.865; r = 0.930** \quad (9)$$

$$Y_{\mathrm{DM}} = 4.660 + 0.01437\mathrm{K}_1; R^2 = 0.975; r = 0.987** \quad (10)$$

$$Y_{\mathrm{DM}} = 4.874 + 0.02259\mathrm{K}_2; R^2 = 0.957; r = 0.978** \quad (11)$$

$$Y_{\mathrm{DM}} = 5.228 + 0.02593\mathrm{K}_3; R^2 = 0.972; r = 0.986** \quad (12)$$

$$Y_{\mathrm{DM}} = 5.670 + 0.02891\mathrm{K}_4; R^2 = 0.956; r = 0.978** \quad (13)$$

$$Y_{\mathrm{DM}} = 6.347 + 0.04309\mathrm{K}_5; R^2 = 0.991; r = 0.995** \quad (14)$$

where: K0, K1, K2, K3, K4, and K5 = vermicompost application rates of 0, 5, 10, 15, 20, and 25 Mg·ha^{-1}, respectively.

Within the range of treatments evaluated in this study, the optimum rates of nitrogen and vermicompost were not reached, as fresh biomass yield continued to increase with increasing fertiliser application rates.

GROWTH PERFORMANCE

Plant height increased progressively with increasing nitrogen doses, particularly when combined with higher vermicompost rates. The tallest plants (6.45 cm at 21 DAP and 10.34 cm at 28 DAP) were observed under the combined application of 138 kg N·ha^{-1} and 25 Mg·ha^{-1} vermicompost. This result supports the findings by Sreerenjiny and Debbarma (2022), who reported that adequate nitrogen supply enhances vegetative growth by stimulating cell division and elongation.

Leaf area index (*LAI*) also increased significantly, reaching maximum values of 1.839, 3.330, and 13.393 at 14, 21, and 35 DAP, respectively, under the highest vermicompost and nitrogen application rates. This response is consistent with the findings of Kumar *et al.* (2021), who demonstrated that integrated fertilisation sustains higher photosynthetic capacity throughout the growth period. The observed response reflects an additive interaction, whereby vermicompost improved soil water retention and nutrient availability, supporting sustained leaf expansion under dryland conditions.

The number of leaves did not differ significantly among treatments, indicating that yield improvement was primarily associated with increased leaf area rather than leaf number. This highlights the importance of leaf morphology in determining photosynthetic efficiency and biomass accumulation.

YIELD COMPONENTS

The combined application of 25 Mg·ha^{-1} vermicompost and 138 kg N·ha^{-1} produced the highest fresh biomass yield (238.52 Mg·ha^{-1}) and oven-dry yield (12.53 Mg·ha^{-1}). Compared with the unfertilised control, biomass yields increased markedly; however, these values should be interpreted as short-term responses obtained under a single growing season and site-specific conditions. Similar magnitudes of yield improvement have been reported in other Brassica species under integrated nutrient regimes (Kumar *et al.*, 2021).

Strong linear relationships between fertiliser dose and yield suggest that increasing nutrient availability consistently enhanced biomass accumulation. Similar response trends under integrated nutrient regimes have also been reported for Brassica crops by Kumar *et al.* (2021) and Malav, Salvi and Jat (2024).

SOIL PHYSICAL AND CHEMICAL IMPROVEMENTS

Vermicompost significantly improves soil physical properties, as indicated by increased porosity and permeability and reduced bulk density. Similar effects have been widely reported, with vermicompost application shown to enhance soil aggregation, infiltration rate, and structural stability by increasing organic binding agents and biological activity in soil (Castellini *et al.*, 2024; Hermawan *et al.*, 2024).

Combined fertilisation increased soil total nitrogen, organic carbon, and leaf nitrogen content. These improvements are consistent with recent studies indicating that vermicompost application enhances soil physical properties, nutrient availability, and biological activity (Yıldız, Altunok and Yerdelen, 2025). Increased soil organic carbon contributes to improved cation exchange capacity, buffering capacity, and long-term soil resilience (Ghosh *et al.*, 2020). Despite these improvements, high nitrogen application rates on sandy coastal soils may increase the risk of nitrate leaching due to their low water-holding capacity. As nitrogen losses were not measured in this study, the results should be interpreted cautiously, and future studies should explicitly quantify nitrogen leaching to evaluate its environmental risks.

These findings corroborate reports by Manzoor *et al.* (2024) and Castellini *et al.* (2024), who demonstrated that vermicompost amendments can improve soil organic carbon and overall soil quality, even in degraded soils. In particular, vermicompost has been shown to enhance soil carbon sequestration through increased microbial activity and improved stabilisation of organic matter within soil aggregates, leading to measurable increases in soil organic carbon during a single cropping cycle under favourable conditions.

COMPARATIVE ANALYSIS WITH PREVIOUS STUDIES

In contrast to studies relying solely on inorganic nitrogen fertilisation, which reported limited yield improvement in mustard grown on light-textured soils, the present study demonstrated substantially higher biomass production under integrated nutrient management. The inclusion of vermicompost likely reduced nutrient losses, enhanced soil water retention, and delayed yield saturation commonly observed in sandy soils lacking organic amendments (Sreerenjiny and Debbarma, 2022; Malav, Salvi and Jat, 2024; Raksun *et al*., 2024). Similar yield increases have been documented in other crops, where integrated organic–inorganic fertilisation significantly improved productivity through better nutrient synchrony and soil moisture conservation (Castellini *et al*., 2024; Hermawan *et al*., 2024), while Lautt *et al*. (2021) reported a doubling of yield in tropical peatlands under integrated fertilisation systems.

PRACTICAL IMPLICATIONS

The findings indicate that integrated vermicompost and nitrogen fertilisation can substantially improve mustard productivity and soil quality in coastal dryland systems. However, this experiment was conducted at a single location and over one cropping season, and therefore the results represent only short-term responses. Economic feasibility, labour requirements, and environmentally optimal fertiliser rates were not evaluated in this study and should be addressed in future research.

CONCLUSION

The combined application of vermicompost and nitrogen significantly influenced the growth, yield, and selected soil physical and chemical properties of mustard greens (*Brassica juncea* L.) cultivated under coastal dryland conditions in Nusa Lembongan. The results demonstrated that integrated fertilisation produced additive and interactive effects on plant height, leaf area index, biomass yield, and soil quality indicators compared to the application of either input alone. Higher rates of vermicompost combined with nitrogen consistently enhanced fresh and oven-dried biomass yields, primarily through improvements in leaf expansion and photosynthetic capacity rather than increases in leaf number. Improvements in soil physical properties, including reduced bulk density and increased porosity and permeability, indicate that vermicompost played a critical role in improving soil structure and water dynamics in sandy coastal soils. Chemically, increases in soil organic carbon and nitrogen content suggest improved nutrient availability during the cropping period. However, these findings represent short-term responses obtained from a single location and one growing season and therefore should not be interpreted as evidence of long-term soil improvement. Moreover, although higher nitrogen and vermicompost rates resulted in greater yields, potential environmental risks such as nitrogen leaching in sandy soils were not assessed and should be considered. From a practical perspective, integrated nutrient management using vermicompost and nitrogen shows promise for improving mustard productivity in coastal drylands. Nevertheless, the feasibility of applying high vermicompost rates (e.g., 25 $Mg \cdot ha^{-1}$) requires further evaluation through cost–benefit analysis and multi season trials. Future research should focus on optimising fertiliser combinations, assessing environmental impacts, and validating these findings across different seasons and locations to support broader application.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interest.

REFERENCES

Anwar, K., Trisnawaty, A.R. and Hasanuddin, F. (2024) "Pertumbuhan dan produksi tanaman sawi (*Brassica juncea* L.) pada berbagai jenis pupuk organik [Growth and yield response of mustard greens (*Brassica juncea* L.) to various types of manures]," *Jurnal Penelitian Pertanian Terapan*, 2(2), pp. 119–124. Available at: https://ojs.polipangkep.ac.id/index.php/prp/article/view/518/469.

Budiasih, R. *et al.* (2018) "Effect of chicken fertilizer combination and concentration of organic liquid fertilizer (LOF) on growth and results of sawi plant (*Brassica juncea* L.) Shinta variety," *Asian Journal of Agriculture and Rural Development*, 8(2), pp. 204–209. Available at: https://doi.org/10.18488/journal.1005/2018.8.2/1005.2.204.209.

Castellini, M. *et al.* (2024) "Impact of vermicompost addition on water availability of differently textured soils," *Heliyon*, 10(15), e35699. Available at: https://doi.org/10.1016/j.heliyon.2024.e35699.

Dey, B. *et al.* (2024) "Optimization of chemical fertilizer through integrated nutrient management (INM) approach and its effect on growth and yield of *Brassica juncea* L.," *Asian Journal of Soil Science and Plant Nutrition*, 10(1), pp. 64–74. Available at: https://doi.org/10.9734/ajsspn/2024/v10i1211.

Ejraei, A., Ghehsareh, A.M. and Hodaji, M. (2023) "A new approach to develop nitrogen fertilizer recommendation: A case study for Washington Navel Orange cultivar," *Journal of Plant Nutrition*, 46, pp. 3715–3725. Available at: https://doi.org/10.1080/01904167.2023.2211599.

Ghosh, D. *et al.* (2020) "Nutrient's supplementation through organic manures influence the growth of weeds and maize productivity," *Molecules*, 25(21), 4924. Available at: https://doi.org/10.3390/molecules25214924.

Hermawan, B. *et al.* (2024) "Changes in soil physical properties following applications of vermicompost superimposed with liquid organic fertilizer," *Journal of Tropical Soils*, 29(2), 107–113. Available at: https://doi.org/10.5400/jts.2024.v29i2.107-113.

Huizil, O. *et al.* (2024) "Integrating NDVI, SPAD, and canopy temperature for strategic nitrogen and seeding rate management to enhance yield, quality, and sustainability in wheat cultivation," *Plants*, 13, 444. Available at: https://doi.org/10.3390/plants13111574.

Ilhamiyah, S. *et al.* (2019) "Agro-ecosystem management on green mustard plants in wetlands during dry season," *Journal of Wetlands Environmental Management*, 7(1), pp. 41–49. Available at: https://www.researchgate.net/publication/336794274_Agroecosystem_Management_on_Green_Mustard_Plants_in_Wetlands_during_Dry_Season.

Kumar, V. *et al.* (2022) "Integrated nutrient management for sustainable productivity and quality of Indian mustard (*Brassica juncea* L.) in semi-arid region," *Agricultural Research*, 11(4), pp. 505–514.

Kwiatkowski, C.A., Haliniarz, M. and Harasim, E. (2020) "Weed infestation and health of organically grown chamomile (*Chamomilla recutita* (L.) Rausch.) depending on selected foliar sprays and row spacing," *Agriculture*, 10(5), 168. Available at: https://doi.org/10.3390/agriculture10050168.

Lautt, B.S. *et al.* (2021) "Effects of vermicompost and NPK fertilizer to growth and yield of mustard plant (*Brassica juncea* L.) on tropical peatlands," *Journal of Tropical Peatlands*, 10(2), pp. 23–28. Available at: https://doi.org/10.52850/jtpupr.v10i2.3032.

Loki, J. (2025) "Nutrient deficiencies and their effects on plant growth and metabolism," *Journal of Plant Biochemistry and Physiology*, 13, 367. Available at: https://doi.org/10.35248/2329-9029.25.13.367.

Manzoor, A. *et al*. (2024) "Vermicompost: A potential organic fertilizer for sustainable vegetable cultivation," *Scientia Horticulturae*, 336, 113443. Available at: https://doi.org/10.1016/j.scienta.2024.113443.

Malav, J.K., Salvi, N.N. and Jat, A.L. (2024) "Effect of organic and inorganic sources of nitrogen on productivity, profitability and soil fertility status after harvest of mustard (*Brassica juncea* L.)," *Journal of Oilseed Brassica*, 15(1), pp. 76–80. Available at: https://doi.org/10.56093/job.v15i1.

Mkhonza, N.P., Buthelezi-Dube, N.N. and Muchaonyerwa, P. (2020) "Effect of lime application on nitrogen and phosphorus availability in humid soils," *Scientific Reports*, 10(1), pp. 1–12. Available at: https://doi.org/10.1038/s41598-020-65501-3.

Musei, S.K. *et al*. (2024) "Sandy soil reclamation technologies to improve crop productivity and soil health: A review," *Frontiers in Soil Science*, 4, 1345895. Available at: https://doi.org/10.3389/fsoil.2024.1345895.

Nackley, L. *et al*. (2024) "Investigating the benefits of tectonite dust as an amendment for bark substrates and dryland crops," *Plants*, 13, 126. Available at: https://doi.org/10.3390/plants13010126.

Pradita, A. and Janicka, M. (2025) "Predicting plant establishment: Germination responses of five *Arrhenatherion* alliance species from two distinct climatic origins," *Journal of Water and Land Development*, 64, pp. 148–154. Available at: https://doi.org/10.24425/jwld.2025.153527.

Raksun, A. *et al*. (2024) "Vegetative growth analysis of mustard green (*Brassica juncea* L.) consequences of vermicompost and urea fertilizer treatment," *Jurnal Biologi Tropis*, 24(3), pp. 800–806. Available at: https://doi.org/10.29303/jbt.v24i3.7517.

Sande, T.J. *et al*. (2024) "Enhancing sustainable crop production through integrated nutrient management: A focus on vermicompost, bio-enriched rock phosphate, and inorganic fertilisers – A systematic review," *Frontiers in Agronomy*, 6, 1422876. Available at: https://doi.org/10.3389/fagro.2024.1422876.

Sreerenjiny, S. and Debbarma, V. (2022) "Influence of integrated nutrient management on growth and yield of mustard (*Brassica juncea* L.)," *International Journal of Plant & Soil Science*, 34(21), pp. 435–442. Available at: https://doi.org/10.9734/ijpss/2022/v34i2131281.

Tang, L. (2025) "Soil fertility, plant nutrition and nutrient management," *Plants*, 24(34). Available at: https://doi.org/10.3390/plants14010034.

Vadez, V. *et al*. (2024) "Crop traits and production under drought," *Nature Reviews Earth & Environment*, 5, pp. 211–225. Available at: https://doi.org/10.1038/s43017-023-00514-w.

Venkatesh, I. *et al*. (2023) "Effect of integrated nutrient management on dynamics of nutrient availability at various intervals in mustard (*Brassica juncea* L.) crop," *International Journal of Environment and Climate Change*, 13(10), pp. 2386–2396. Available at: https://doi.org/10.9734/ijecc/2023/v13i102903.

Winberg, J., Smith, H.G. and Ekroos, J. (2023) "Bioenergy crops, biodiversity and ecosystem services in temperate agricultural landscapes – A review of synergies and trade-offs," *Global Change Bioenergy*, 15, pp. 1204–1220. Available at: https://doi.org/10.1111/gcbb.13092.

Xue, J. and Bakker, M.R. (2022) "Enhancement in soil fertility, early plant growth and mycorrhizal colonization by vermicompost application," *Soil and Sediment Contamination*, 31, pp. 1662–1676. Available at: https://doi.org/10.1007/s11368-022-03180-5.

Yıldız, N., Altunok, F. and Yerdelen Uncu, G.E. (2025) "Effect of vermicompost fertilizer application on soil properties: A review," *International Journal of Innovative Approaches in Agricultural Research*, 9(2), pp. 142–151. Available at: https://doi.org/10.29329/ijiaar.2025.1321.7.