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Integrated Vermicompost and Mineral Fertilization Improves Soil Fertility and Nutrient-Use Efficiency in Sandy Soils of Arid Environments

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ABSTRACT

Sandy soils in arid environments are characterized by low organic matter, poor nutrient retention, and high susceptibility to nutrient losses, limiting crop productivity and sustainability. Integrated nutrient management combining organic amendments with mineral fertilizers offers a promising strategy to enhance soil fertility and nutrient-use efficiency under such conditions. This study evaluated the interactive effects of vermicompost (0, 5, 10, and 15 t ha^{-1}) and graded mineral fertilization levels (100%, 85%, 70%, and 55% of recommended NPK rates) on soil fertility dynamics, nutrient-use efficiency, and barley (*Hordeum vulgare* L.) productivity over two growing seasons in sandy soils.

Results showed that both vermicompost and mineral fertilization significantly ($p \leq 0.05$) influenced soil properties and crop performance, with strong interaction effects. Integrated application improved soil organic matter, total nitrogen, and available phosphorus and potassium, reflecting enhanced nutrient retention and cycling. The highest grain yield (~6.0 t ha^{-1}) was obtained under combined application of 100% mineral fertilization and 10 t ha^{-1} vermicompost, while moderate reductions in mineral fertilizer (70-85%) with vermicompost maintained relatively high productivity.

Vermicompost application increased nutrient-use efficiency by improving soil physicochemical properties and synchronizing nutrient availability with crop demand. However, sole reliance on organic inputs did not fully compensate for reduced mineral fertilization under high productivity conditions. The findings highlight the synergistic role of integrated organic–mineral fertilization in enhancing soil fertility, optimizing nutrient dynamics, and supporting sustainable crop production in arid sandy ecosystems.

Keywords: vermicompost, grain quality, nutrient efficiency, organic fertilization, soil nutrient dynamics.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is one of the most widely cultivated cereal crops worldwide, valued for its adaptability to diverse agroecological conditions and its importance in food, feed, and malting industries. In arid and semi-arid regions such as Egypt, barley is predominantly grown in reclaimed sandy soils, where low inherent fertility, poor structure, and limited water-holding capacity impose significant constraints on crop productivity (Elsayed et al., 2024). Under such conditions, yield improvement has traditionally relied on the application of mineral fertilizers to meet crop nutrient demands. However, prolonged dependence on synthetic fertilizers without adequate organic inputs can lead to soil degradation, increased salinity, reduced biological activity, and environmental concerns associated with nutrient losses and pollution (Bhatt et al., 2019).

In response to these challenges, there is increasing emphasis on sustainable nutrient management approaches that integrate organic and inorganic inputs. Vermicompost, a stabilized organic amendment produced through the biological activity of earthworms, has emerged as a promising component of such systems. It is characterized by a balanced nutrient composition, high microbial

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activity, and the presence of bioactive compounds that enhance plant growth. Numerous studies have demonstrated that vermicompost improves soil physical properties, including aggregation and water retention, while also enhancing nutrient availability and microbial-mediated nutrient cycling (Patra and Parihar 2023; Abou-El-Hassan et al., 2024). Its incorporation into fertilization programs has been shown to improve plant physiological performance, increase nutrient-use efficiency, and promote soil biological health (Bhanwaria et al., 2022; Abou-El-Hassan et al., 2024; Gosa et al., 2025)

The combined use of vermicompost and mineral fertilizers has been reported to enhance barley growth, yield, and grain quality, particularly in nutrient-poor and sandy soils (Ozyazici and Turan 2021; Kumar et al., 2024; Shilev et al., 2024). Such integrated nutrient management strategies improve nitrogen uptake efficiency, reduce nutrient losses, and increase soil organic matter, thereby contributing to more resilient and sustainable production systems under water-limited conditions (Arebu 2022; Yu et al., 2024). These benefits are especially relevant in sandy soils, where rapid nutrient leaching and low organic carbon content limit the effectiveness of conventional fertilization practices.

Despite the growing body of evidence supporting integrated fertilization, the optimization of vermicompost application rates in combination with reduced mineral fertilizer inputs for barley production under Egyptian sandy soils remains insufficiently explored. There is a need to quantify the extent to which vermicompost can enhance nutrient-use efficiency and sustain productivity under reduced mineral fertilization regimes.

Therefore, the present study was conducted to evaluate the interactive effects of different vermicompost application rates and graded levels of mineral fertilization on barley growth, yield, grain quality, and soil fertility. The overarching objective was to identify efficient and sustainable nutrient management strategies that enhance crop productivity and soil health while reducing reliance on synthetic fertilizers in sandy soil environments.

MATERIAL AND METHODS

Experimental Site and Soil Analysis

The experiment was conducted over two successive winter seasons at a private farm, Alexandria Desert Road, Egypt (30.9000° N, 29.6833° E). The site experiences an arid climate, low rainfall, and sandy-textured soil. Composite soil samples were collected from the top 0-30 cm depth. The samples were air-dried, sieved through a 2 mm mesh, and analyzed for key physico-chemical properties. Soil pH and EC were measured in a 1:2.5 soil-to-water extract using digital meters. Organic matter was determined using the Walkley and Black (1934) method, total nitrogen by Kjeldahl digestion, available phosphorus by Olsen and Sommers (1982) method, and available potassium using flame photometry. The soil texture was determined using the hydrometer method. The farm is privately owned by the author, and thus no special permissions were required to conduct the experiments.

Treatments and Experimental Design

The study followed a factorial arrangement in a randomized complete block design (RCBD) with three replications. Four levels of mineral fertilizer application were tested: 100% (recommended dose by the Egyptian Ministry of Agriculture), 85%, 70%, and 55% of the recommended NPK fertilizer rates. The recommended dose was 90 kg N. ha^{-1}, 30 kg P_2O_5. ha^{-1}, and 24 kg K_2O. ha^{-1}. Each fertilizer level was combined with three vermicompost rates: 5, 10, and 15 tons per hectare, and 100% NPK without application of vermicompost as control.

The vermicompost used was locally sourced and derived from decomposed cow manure and crop residues, processed by *Eisenia fetida* earthworms. It was characterized by an organic matter content of 26.5%, total nitrogen of 1.6%, available phosphorus of 0.9%, potassium of 1.2%, and a C:N ratio of 13.5. The material had a nearneutral pH (7.3) and EC of 3.7 dS. m^{-1}. it was applied and incorporated into the top 15 cm soil layer two weeks before sowing.

Plant Material and Crop Management

Barley (*Hordeum vulgare* L., cv. Giza 123), obtained from the Field Crops Research Institute, Agricultural Research Center (ARC) in Giza, Egypt, was used in both growing seasons at a seed rate of 130 kg. ha^{-1}. Sowing was conducted on November 20, 2023, and November 18, 2024, during the first and second seasons, respectively, by using the manual drilling method in rows spaced 20 cm apart, at a depth of approximately 3-4 cm. Each experimental sub plot measured 9 m^2. Other agricultural practices were applied as the recommendations. Plants were harvested on April 10, 2024, and April 8, 2025.

Measured Traits

At harvest, data were collected from plants of 1 m^2 area per sub plot for the following parameters:

- Growth traits: Plant height (cm) from soil surface to tip of the spike, Number of tillers per plant (average of productive tillers).
- Yield and its component: Spike length (cm) measured without awns, Number of grains per spike (manually counted), 1000-grain weight (g) based on three subsamples, and Grain yield (ton. ha^{-1}) extrapolated from sub plot yield.
- Grain quality traits: Crude protein (%) determined using the Kjeldahl method, and Ash content (%) via dry ashing at 550°C (AOAC, 2016).
- Post-harvest Soil Analysis: After harvesting, soil samples were again collected from each sub plot (0-30 cm depth) to assess the impact of treatments on soil fertility. The same procedures as pre-sowing were applied to measure soil pH, EC, available nitrogen, phosphorus, and potassium. Comparative analysis was conducted between pre- and post-cultivation values to evaluate changes in soil quality resulting from the applied mineral fertilizer and vermicompost level interactions.

Statistical Analysis

All measured variables were subjected to analysis of variance (ANOVA) for a factorial experiment arranged in a randomized complete block design (RCBD) using the MSTAT-C statistical software package (version 2.10; Michigan State University, 1991). The main effects of mineral fertilizer levels, vermicompost application rates, and their interactions were evaluated.

Treatment means were separated using the Least Significant Difference (LSD) test at the 0.05 probability level. Standard errors of the mean (SE) were calculated for all measured traits to quantify experimental variability, and corresponding LSD values were reported to facilitate mean comparisons.

All statistical procedures followed standard methodologies for agricultural experimentation as outlined by Gomez and Gomez (1984), ensuring the robustness and reliability of the analysis.

RESULTS AND DISCUSSION

Treatment effects and interaction between mineral fertilization and vermicompost

Analysis of variance showed that mineral fertilizer level, vermicompost (VC) rate, and their interaction significantly ($p \leq 0.05$) affected all measured variables (Tables 1-3). The significant interaction effect indicates that barley response to VC depended on mineral fertilizer level, confirming that nutrient availability in sandy soils is controlled by both nutrient supply and retention capacity. Similar interaction patterns have been reported in cereal systems under integrated nutrient management, where organic amendments enhance the efficiency of mineral fertilizers rather than acting independently (Kumar et al., 2024; Terefe et al., 2024).

Across most parameters, treatments combining higher mineral fertilizer levels with VC produced significantly greater values than low-input treatments, reflecting a synergistic effect. This interaction can be explained by the complementary roles of mineral fertilizers as immediate nutrient sources and VC as a regulator of nutrient retention, microbial activity, and soil physical properties (Garcia et al., 2017; Bhatt et al., 2019).

Vegetative growth responses

Vegetative growth traits were significantly improved by integrated fertilization (Figures 1-3). Plant height increased significantly with increasing VC rates, particularly under 85-100% mineral fertilization (Figure 1). This increase is attributed to enhanced nitrogen availability and improved soil moisture retention, both of which promote cell elongation and biomass accumulation. Similar findings were reported by Patra and Parihar (2023), who demonstrated that vermicompost enhances nutrient availability and plant growth through improved soil biological activity.

Tillering showed a strong and significant response to treatment combinations (Figure 2), with the highest values observed under high mineral fertilizer combined with 10-15 t ha^{-1} VC. Tillering in cereals is highly dependent on nitrogen availability during early growth stages; thus, the observed increase reflects improved nitrogen-use efficiency and root development. Abou-El-Hassan et al. (2024) also reported that organic amendments stimulate root growth and enhance nutrient uptake, leading to improved tiller formation.

Spike length increased significantly with increasing VC rates (Figure 3), indicating improved reproductive development. This can be linked to enhanced assimilate production and nutrient availability during the reproductive phase. Similar improvements in spike characteristics under integrated fertilization have been reported by El-Akhdar et al. (2024), highlighting the role of balanced nutrient supply in reproductive development.

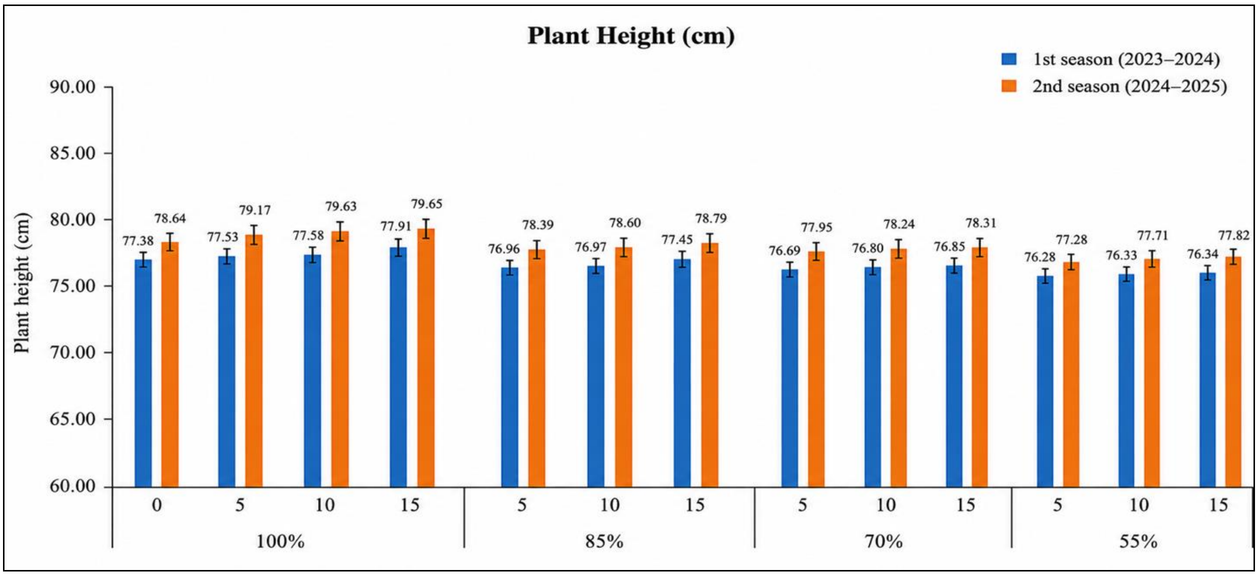

Figure 1. Effect of Mineral Fertilizer and Vermicompost Levels on Plant Height of Barley During the 2023-2024 and 2024-2025 Growing Seasons. Values represent means of replicates ± standard error (SE). L.S.D $_{\text{at 5\%}}$; 4.131 and 4.219 for first and second season, respectively.

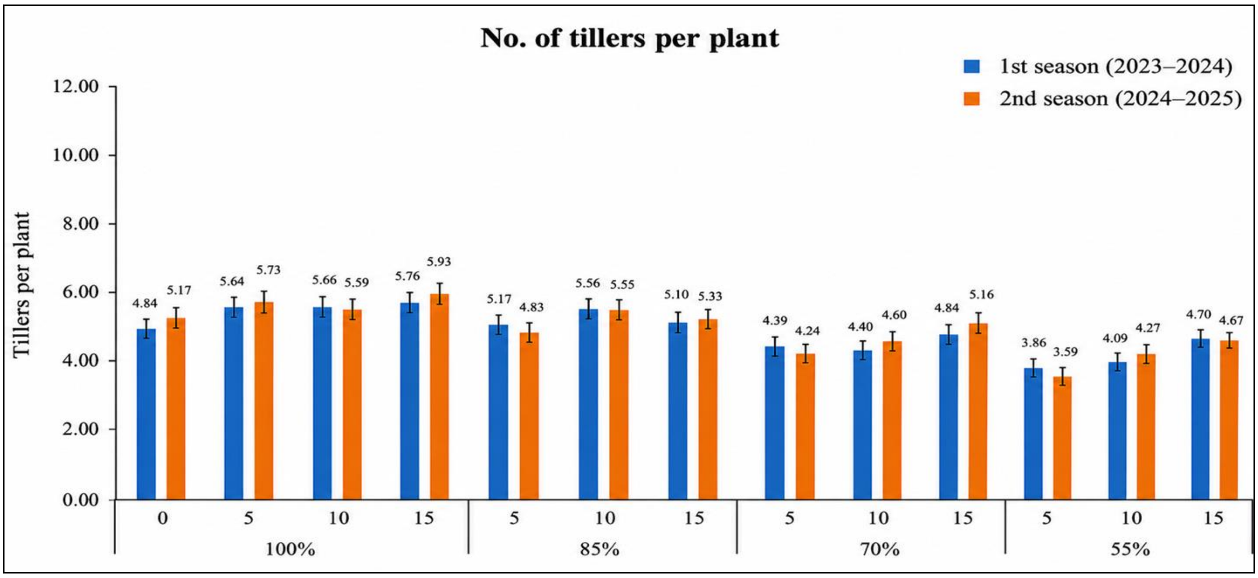

Figure 2. Number of Tillers per Plant as Influenced by Mineral Fertilizer and Vermicompost Applications in Barley Over 2023/24 and 2024/25 Seasons. Values represent means of replicates ± standard error (SE). L.S.D $_{at\ 5\%}$; 0.386 and 0.351 for first and second season, respectively.

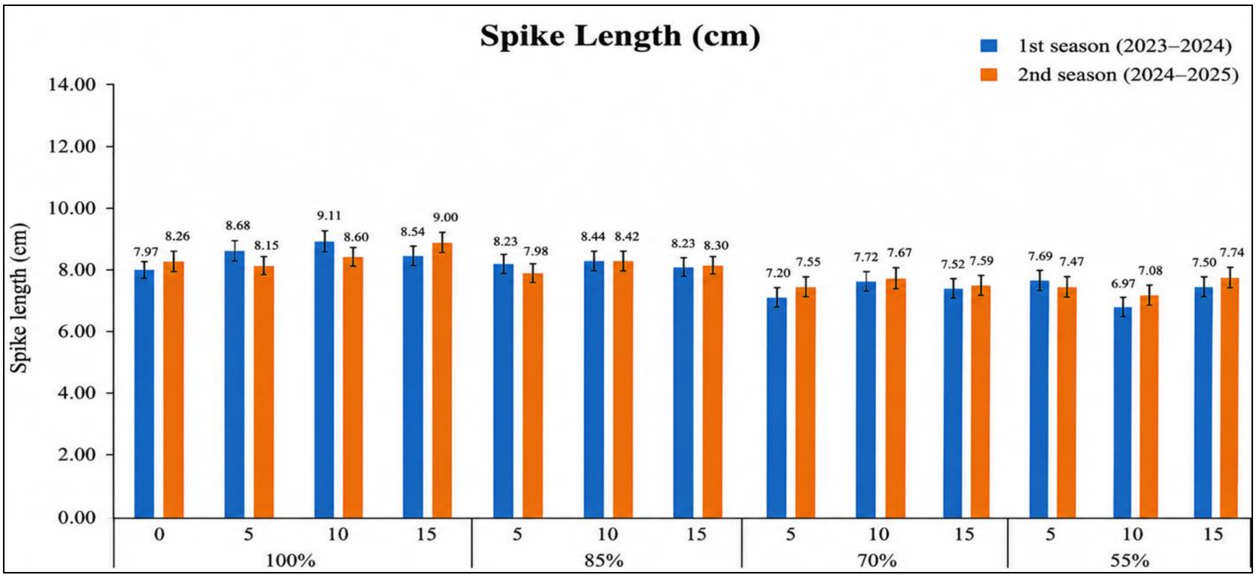

Figure 3. Impact of Combined Vermicompost and Mineral Fertilizer Rates on Spike Length of Barley in 2023/24 and 2024/25 season. Values represent means of replicates ± standard error (SE). L.S.D $_{at\ 5\%}$; 0.489 and 0.475 for first and second season, respectively.

Yield components and grain yield

Yield components responded differently to treatment combinations (Fig. 4). Grain number per spike showed relatively limited variation, with several treatments being statistically comparable, suggesting that this trait is less responsive to nutrient supply. However, 1000-grain weight increased significantly with VC application, particularly under adequate mineral fertilization, indicating that grain filling is highly sensitive to sustained nutrient availability.

Interestingly, the maximum grain yield was observed at 10 t ha^{-1} VC rather than the highest application rate (15 t ha^{-1}), suggesting the existence of an optimal balance between organic and mineral nutrient inputs. This indicates that excessive VC application does not necessarily translate into proportional yield gains. The reduced efficiency at higher VC rates may be attributed to temporary nitrogen immobilization during organic matter decomposition, slight increases in soil electrical conductivity, or nutrient imbalances affecting plant uptake. These findings highlight the importance of optimizing integrated nutrient management strategies rather than maximizing individual input levels. Similar results have been reported by Terefe et al. (2024), who found that integrated fertilization significantly increased barley yield through improved nutrient-use efficiency.

In contrast, reduced mineral fertilizer levels resulted in significantly lower yields, even when combined with high VC rates, indicating that VC alone cannot fully substitute for mineral fertilizers. This finding agrees with Bhatt et al. (2019), who concluded that organic amendments enhance nutrient-use efficiency but do not replace mineral nutrient supply in high-demand cropping systems.

The yield improvement can be mechanistically explained by increased cation exchange capacity, reduced nutrient leaching, improved nutrient synchronization with crop demand, and enhanced microbial activity (Garcia et al., 2017; Hasan et al., 2024).

Grain quality

Grain quality parameters were significantly improved under integrated fertilization (Figure 5). Crude protein content increased significantly with increasing nutrient availability, reaching maximum values under treatments combining full mineral fertilization with VC. This reflects improved nitrogen uptake and assimilation, supported by sustained nitrogen mineralization and reduced losses. Similar increases in grain protein under integrated nutrient management have been reported by Karol et al. (2023) and Hegab (2024).

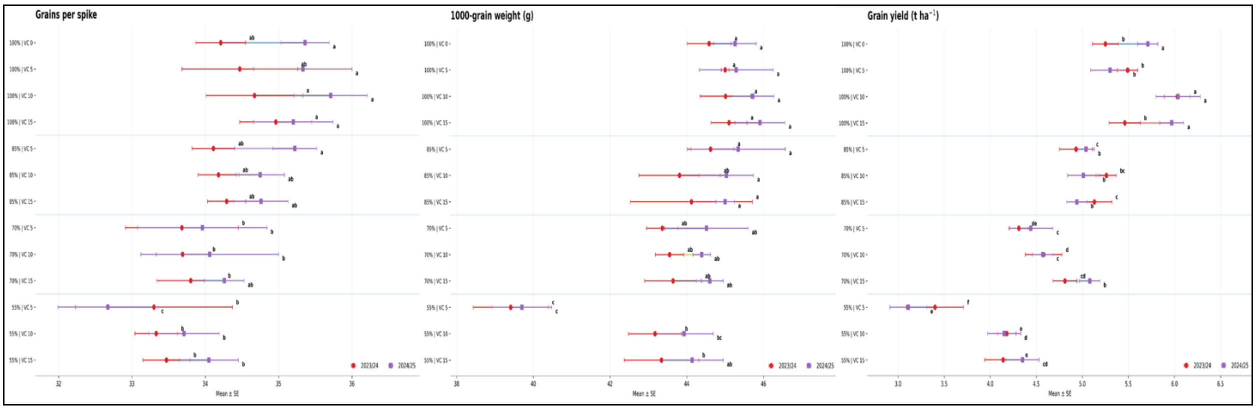

Figure 4. Effect of Mineral Fertilizer and Vermicompost Rates on Yield Components of Barley (Grains per Spike, 1000-Grain Weight, and Grain Yield) Across 2023/24 and 2024/25 Growing Seasons. Y axis for treatments and X axis represent means of the studied trait. Means within different letters indicate significant differences among treatments at $p \leq 0.05$ according to the Least Significant Difference (LSD) test.

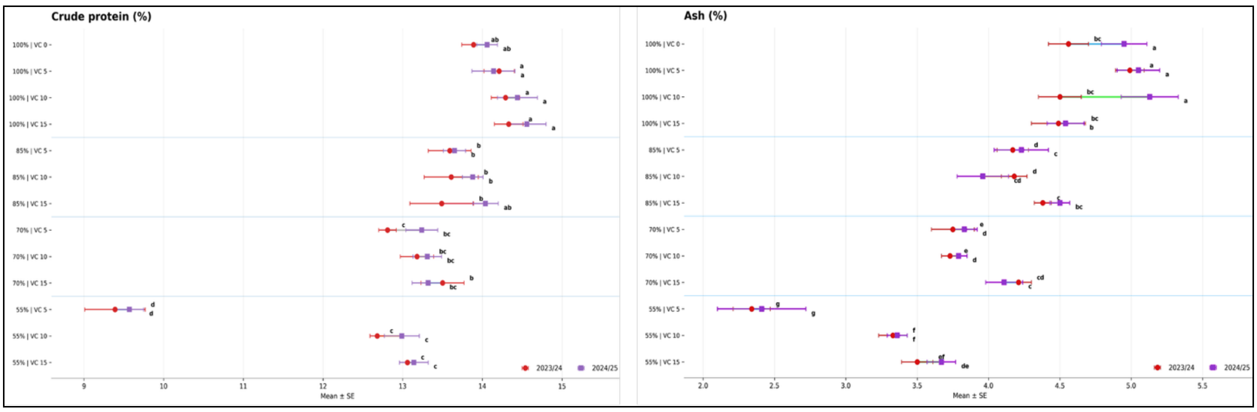

Figure 5. Influence of mineral fertilizer and vermicompost combinations on barley grain quality parameters. Y axis for treatments and X axis represent means of the studied trait. Means within different letters indicate significant differences among treatments at $p \leq 0.05$ according to the Least Significant Difference (LSD) test.

Ash content also increased significantly with VC application, indicating enhanced mineral accumulation in grains. This is likely due to improved availability and uptake of macro- and micronutrients under organic amendment application (Ahmed, 2023). Importantly, the simultaneous increase in yield and protein content indicates improved nitrogen-use efficiency without dilution effects, which is a key indicator of balanced nutrient management.

Soil fertility and system-level implications

Vermicompost application significantly improved soil fertility parameters (Figure 6), including organic matter, total nitrogen, available phosphorus, and potassium. The highest values were observed under treatments receiving higher VC rates, indicating substantial improvement in soil quality. Increases in organic matter (up to ~74.5%) are particularly important in sandy soils, where low organic carbon limits nutrient retention and productivity (Garcia et al., 2017; Bhatt et al., 2019). The observed improvements in nutrient availability can be attributed to direct nutrient inputs from VC, enhanced microbial activity, improved soil aggregation, and increased cation exchange capacity (Patra and Parihar, 2023; Hasan et al., 2024). The slight increase in electrical conductivity and decrease in soil pH under VC treatments indicate improved nutrient availability without reaching harmful thresholds. These changes highlight the role of VC in restoring soil fertility and enhancing nutrient cycling in degraded soils (Garcia et al., 2017; Hasan et al., 2024).

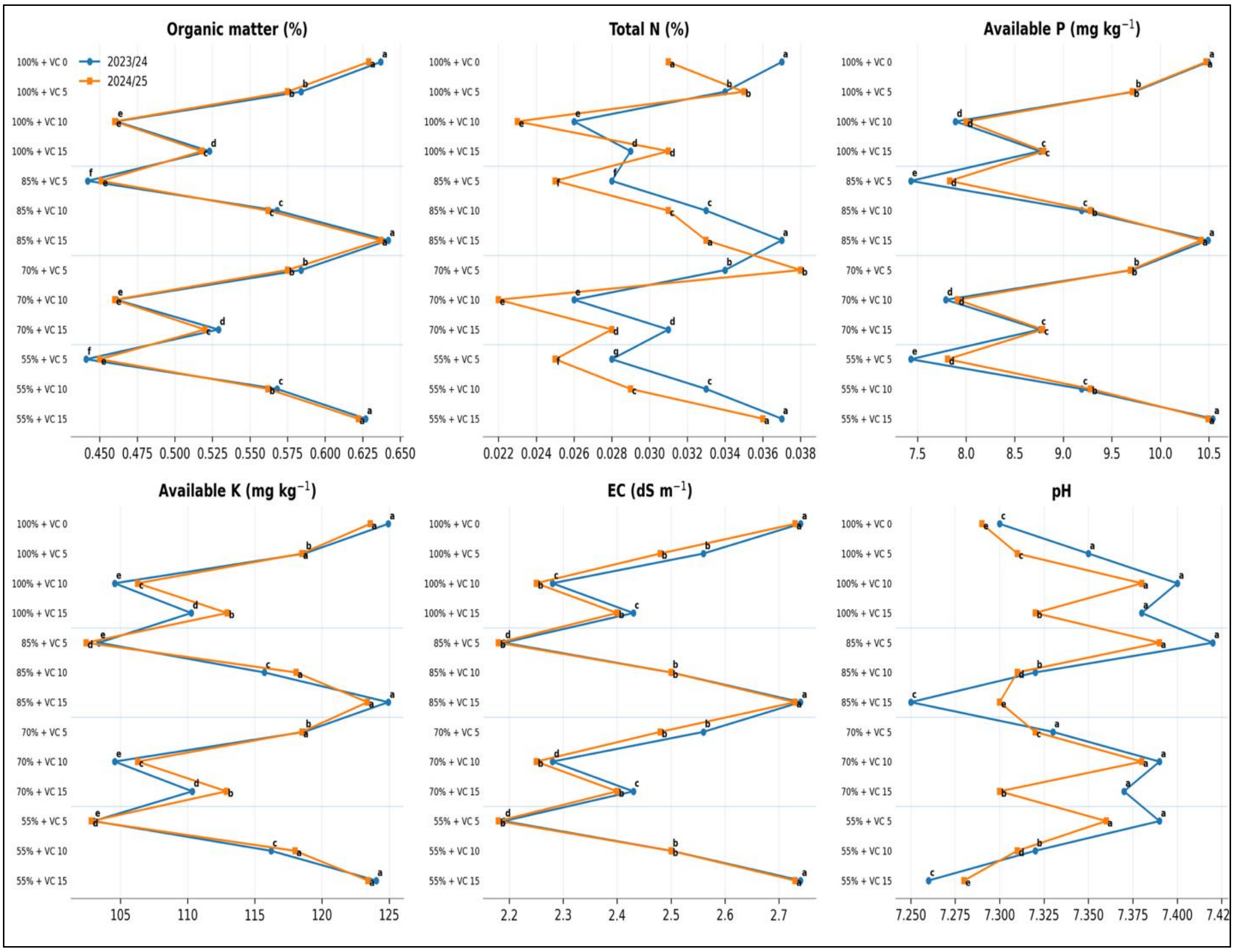

Figure 6. Post-Harvest Soil Fertility Characteristics as Affected by Mineral Fertilizer and Vermicompost Levels during 2023/24 and 2024/25 Seasons. Y axis for treatments and X axis represent means of the studied trait. Means within each line followed by different letters indicate significant differences among treatments at p ≤ 0.05 according to the Least Significant Difference (LSD) test.

Overall, the results demonstrate a strong soil-plant feedback mechanism in which improvements in soil properties enhance root development, nutrient uptake, and crop performance, while also contributing to long-term soil fertility (Kumar et al., 2024; Shilev et al., 2024). Although vermicompost significantly improved soil fertility parameters, the absence of maximum yield at the highest application rate further supports the concept of nutrient synchronization. Excessive organic inputs may delay nutrient mineralization relative to crop demand, leading to suboptimal nutrient availability during critical growth stages (Hasan et al., 2024; Terefe et al., 2024). As a result, improved soil nutrient reserves do not necessarily translate into optimal nutrient supply at the time of peak crop demand (Gosa et al., 2025).

However, the findings also indicate that maximum productivity requires adequate mineral nutrient supply, with vermicompost functioning primarily as a complementary input that enhances nutrient-use efficiency rather than replacing mineral fertilizers (Bhatt et al., 2019; Terefe et al., 2024). From an agronomic perspective, combining mineral fertilizers with vermicompost optimizes both productivity and sustainability, while from an environmental perspective, this approach reduces nutrient losses, enhances soil carbon sequestration, and improves resilience of sandy soils. These findings support the adoption of integrated nutrient management strategies for sustainable intensification in arid and semi-arid agroecosystems, in line with FAO (2021) recommendations.

Relative changes in soil fertility parameters

The relative changes in soil fertility parameters further elucidate the cumulative effects of integrated nutrient management on soil quality (Figure 7). Across treatments, vermicompost application markedly enhanced soil organic matter (OM), total nitrogen (N), available phosphorus (P), and potassium (K), with the magnitude of improvement strongly dependent on both VC rate and mineral fertilizer level (Bhatt et al., 2019; Hasan et al., 2024).

The highest relative increases were observed under treatments combining higher VC rates with adequate mineral fertilization, with organic matter increasing by up to 74.5% and total nitrogen by 80.5% (Table 4). These substantial gains reflect the dual contribution of vermicompost as both a direct source of organic carbon and nutrients, and as a stimulator of microbial activity and nutrient cycling (Bhanwaria et al., 2022; Hasan et al., 2024). In sandy soils, where organic matter is inherently low, such increases are particularly critical, as they directly improve soil aggregation, water retention, and cation exchange capacity (Garcia et al., 2017; El-Akhdar et al., 2024).

Available phosphorus and potassium also showed marked increases, reaching up to 50.9% and 28.7%, respectively (Figure 8). These improvements can be attributed to enhanced solubilization processes driven by organic acids and microbial activity, as well as reduced fixation and leaching losses (Garcia et al., 2017; Patra and Parihar, 2023). The greater relative increases observed under integrated treatments compared with low-input treatments indicate improved nutrient retention and cycling efficiency (Bhatt et al., 2019; Terefe et al., 2024).

Interestingly, treatments with reduced mineral fertilizer levels combined with high VC rates exhibited substantial relative increases in soil fertility parameters, suggesting that vermicompost plays a dominant role in building residual soil fertility (Hasan et al., 2024; Gosa et al., 2025). However, these relative gains did not always correspond to maximum crop yield, indicating that improvements in soil fertility alone are insufficient to compensate for reduced immediate nutrient availability (Bhatt et al., 2019; Terefe et al., 2024) under high crop demand.

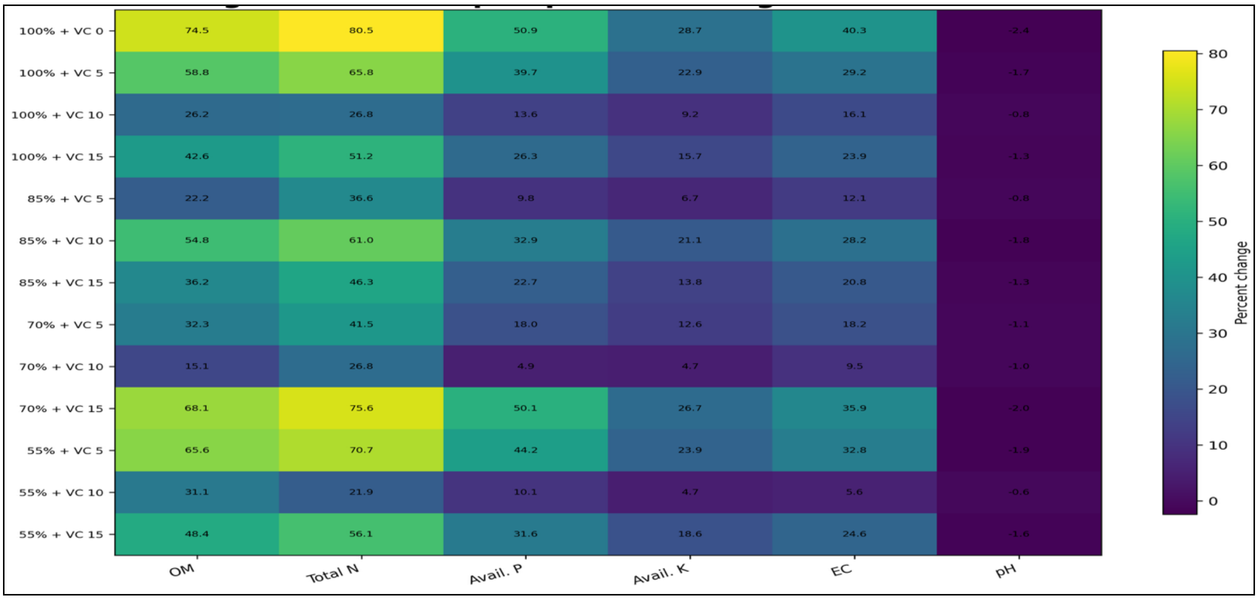

Figure 7. Heatmap of Percent Changes in Key Soil Fertility Parameters from Pre- to Post-Cultivation Due to Varying Vermicompost and Mineral Fertilizer Applications

Electrical conductivity (EC) showed moderate increases across treatments, reflecting the addition of soluble nutrients, while soil pH decreased slightly (Table 4). These changes are consistent with the release of organic acids during vermicompost decomposition and contribute to improved nutrient availability (Garcia et al., 2017; Hasan et al., 2024), particularly in alkaline sandy soils.

Generally, the percentage change analysis confirms that vermicompost significantly enhances soil fertility through both direct nutrient addition and indirect improvements in soil biological and physicochemical properties (Bhanwaria et al., 2022; Hasan et al., 2024). These results highlight the role of integrated nutrient management in promoting long-term soil resilience and nutrient sustainability, even though optimal crop productivity still requires sufficient mineral nutrient inputs (Terefe et al., 2024).

Overall, the statistical analysis demonstrates that integrated nutrient management significantly enhances barley performance and soil fertility (Kumar et al., 2024; Shilev et al., 2024). Treatments combining mineral fertilizers with vermicompost consistently produced superior results compared with low-input treatments, with statistically significant differences observed across most measured parameters. However, although vermicompost markedly improved nutrient-use efficiency and soil quality, it did not fully substitute for mineral fertilizers (Bhatt et al., 2019; Terefe et al., 2024) under the conditions of this study. The occurrence of statistically comparable outcomes among several high-input treatments indicates that optimal nutrient combinations can be achieved without excessive input application. This highlights the potential for designing balanced and resource-efficient fertilization strategies that sustain productivity while minimizing input use and environmental impact (FAO, 2021; El-Akhdar et al., 2024).

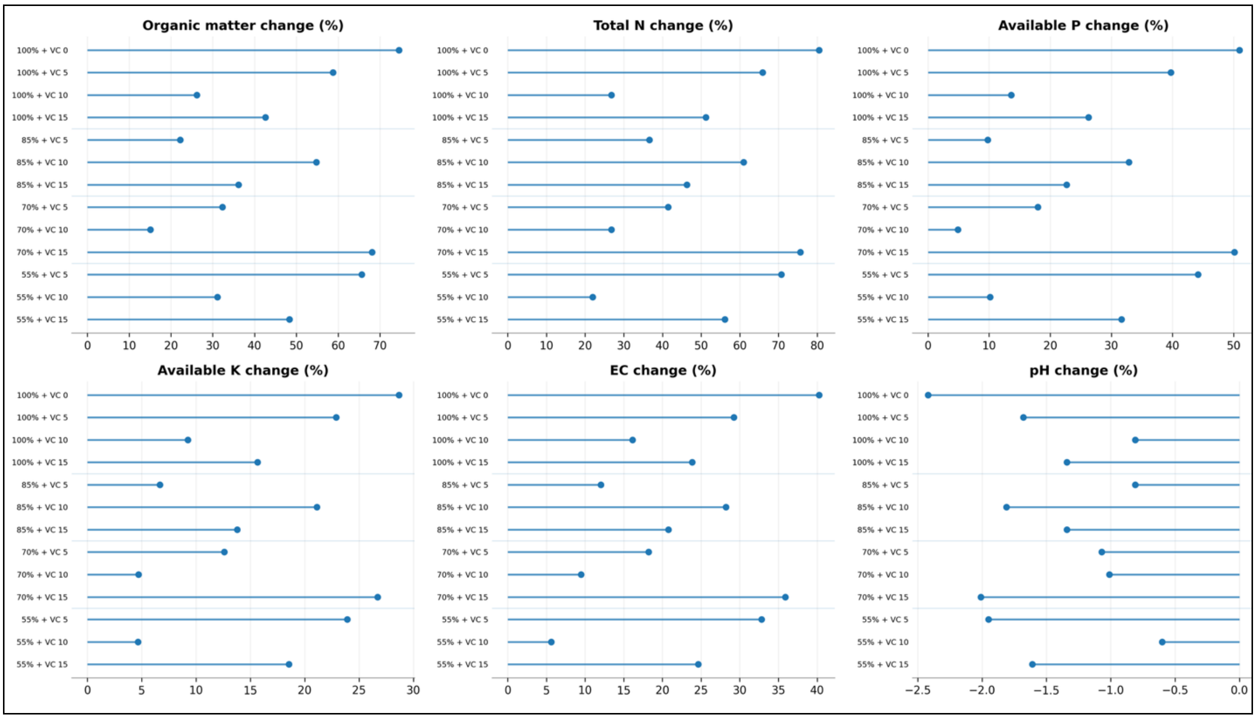

Figure 8. Trait wise percent-change profiles. Y axis for treatments and X axis represent means of percent change

CONCLUSIONS

The present study demonstrates that integrating vermicompost with mineral fertilization significantly enhances barley growth, yield performance, grain quality, and soil fertility under sandy soil conditions. Across two growing seasons, the combined application of mineral fertilizers and vermicompost consistently outperformed low-input treatments, confirming the agronomic and ecological benefits of integrated nutrient management.

The highest grain yield (up to 6.04 t ha^{-1}) was achieved under full mineral fertilization combined with moderate to high vermicompost application (10-15 t ha^{-1}), indicating that vermicompost acts primarily as a complementary input that enhances nutrient-use efficiency rather than fully substituting mineral fertilizers. Nevertheless, treatments combining reduced mineral fertilizer rates (70-85%) with higher vermicompost levels maintained relatively high productivity, suggesting that partial reduction of mineral inputs is feasible without substantial yield penalties when supported by organic amendments.

In addition to yield improvements, vermicompost significantly enhanced grain quality, particularly crude protein and mineral content, reflecting improved nitrogen uptake and nutrient assimilation. Furthermore, marked improvements in soil properties including organic matter, total nitrogen, available phosphorus, and potassium highlight the critical role of vermicompost in restoring soil fertility and improving nutrient retention in coarse-textured soils.

From a sustainability perspective, the integration of vermicompost with mineral fertilization represents a viable strategy for improving crop productivity while enhancing soil health in marginal sandy soils. However, the results also indicate that complete replacement of mineral fertilizers is not supported under the current conditions. Instead, optimized combinations of organic and inorganic nutrient sources are recommended.

The study was conducted over two growing seasons at a single location, which may limit the broader applicability of the results. Therefore, multi-location and long-term studies are required to validate these findings. In addition, the absence of sole reduced mineral fertilizer treatments limits the ability to fully separate the effects of fertilizer reduction from the synergistic effects of vermicompost application. Moreover, soil biological and physical indicators, nutrient-use efficiency indices, and economic analyses were not assessed, which restricts a more comprehensive evaluation of the system. Finally, the relatively high vermicompost rates may present practical and economic constraints for large-scale adoption.Future research should incorporate multi-site trials, longer-term evaluations, comprehensive soil biological assessments, and economic analyses to refine and optimize sustainable nutrient management strategies for barley production.

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REFERENCES

Abou-El-Hassan, S., Abdelaziz, A.M.R.A., Gad El-Moula, M.M.H., Eissa, N.H., Hamed, L.M.M., 2024. *The role of vermiwash and mycorrhiza in enhancing organic head lettuce production.* N. Z. J. Crop Hortic. Sci., 53: 2021-2034. https://doi.org/10.1080/01140671.2024.2436558

Ahmed, I., 2023. *Influence of vermicompost and NPK on the growth and quality of barley*. J. Egypt. Acad. Soc. Environ. Dev. D Environ. Stud., 24: 75-88. https://doi.org/10.21608/jades.2023.310326

AOAC, 2016. *Official Methods of Analysis of AOAC International, 20th ed.* AOAC: Gaithersburg, MD, USA.

Arebu, Y.H., 2022. *Influence of organic fertilizers on productivity of barley: A review*. Agric. Sci. Dig., 42: 121-127. http://dx.doi.org/10.18805/ag.DF-374

Bhanwaria, R., Singh, B., Musarella, C.M., 2022. *Effect of organic manure and moisture regimes on soil physiochemical properties, microbial biomass Cmic:Nmic:Pmic turnover* and yield of mustard grains in arid climate. Plants, 11, 722. https://doi.org/10.3390/plants11060722

Bhatt, M.K., Labanya, R., Joshi, H.C., 2019. *Influence of long-term chemical fertilizers and organic manures on soil fertility - A review*. Univ. J. Agric. Res., 7: 177-188. http://dx.doi.org/10.13189/ujar.2019.070502

El-Akhdar, I., Shabana, M.M.A., El-Khateeb, N.M.M., Elhawat, N., Alshaal, T., 2024. *Sustainable wheat cultivation in sandy soils: Impact of organic and biofertilizer use on soil health and crop yield*. Plants, 13, 3156. https://doi.org/10.3390/plants13223156

Elsayed, M., Dahdouh, S., Poraas, M., Elsawy, M., 2024. *Improving N-fertilization efficiency for barley plant grown on sandy calcareous soil by using organic and biofertilizers*. Zagazig J. Agric. Res., 51: 55-76. https://doi.org/10.21608/zjar.2024.346057

FAO, 2021. *Integrated Nutrient Management for Sustainable Agriculture and Food Security in Africa and the Near East*. Food and Agriculture Organization of the United Nations, Rome, Italy. https://www.fao.org/3/cb4312en/cb4312en.pdf

Garcia, C., Hernandez, T., Coll, M.D., Ondoño, S., 2017. *Organic amendments for soil restoration in arid and semiarid areas: A review*. AIMS Environ. Sci., 4: 640-676. https://doi.org/10.3934/environsci.2017.5.640

Gomez, K.A., and Gomez, A.A., 1984. *Statistical Procedures for Agricultural Research*. 2nd Edition, John Wiley and Sons, New York, 680 p.

Gosa, R., Ketema, T., Eshetu, M., Getachew, G., 2025. *Effects of vermicompost and inorganic fertilizers on the soil properties, yield components, and bread wheat yield in Sinana District, Bale Highlands, Ethiopia*. Asian J. Agric. Allied Sci., 8: 270-278. https://doi.org/10.56557/ajaas/2025/v8i171

Hasan, A.K., Islam, S.S., Jahan, M., Kheya, S.A., Uddin, M.R., Islam, M.S., Khomphet, T., 2024. *Synergistic effects of vermicompost and biochar amendments on soil fertility and wheat productivity in Bangladesh floodplain soils*. Scientifica 2024, 6624984. https://doi.org/10.1155/sci5/6624984

Hegab, R., 2024. *Impact of integrating between mineral nitrogen, vermicompost and biochar on nitrogen-use efficiency and productivity of Panicum plants grown on sandy soil*. Egypt. J. Soil Sci., 64: 1273-1284. https://doi.org/10.21608/ejss.2024.291453.1777

Karol, A., Sharma, P.K., Raj, A., Kehokhunu Rawat, A., Shaji, A., 2023. *Effect of integrated nutrient management on growth and yield of barley (Hordeum vulgare L.)*. Int. J. Environ. Clim. Change, 13: 2968-2976. https://doi.org/10.9734/ijecc/2023/v13i102963

Kumar, M., Shivran, A., Jat, R.D., Anupam, V., 2024. *Effects of different nutrient management methods on growth and yield of barley (Hordeum vulgare L.)*. Int. J. Plant Soil Sci., 36: 687-694. https://doi.org/10.9734/ijpss/2024/v36i64673

MSTAT-C Statistical Software Package, 1991. *A Microcomputer Program for the Design, Management, and Analysis of Agronomic Research Experiments*. Michigan State University: East Lansing, MI, USA.

Olsen, S.R., and Sommers, L.E., 1982. *Phosphorus*. In: Page, A.L. (eds.), Methods of Soil Analysis, Part 2. ASA and SSSA, Madison, WI, USA: 403-430.

Ozyazici, G., and Turan, N., 2021. *Effect of vermicompost application on mineral nutrient composition of grains of buckwheat (Fagopyrum esculentum M.)*. Sustainability, 13, 6004. https://doi.org/10.3390/su13116004

Patra, K., and Parihar, R., 2023. *Enhancing soil fertility and crop nutrition through vermicomposting*. Int. J. Agric. Nutr., 5: 114-117. https://doi.org/10.33545/26646064.2023.v5.i2b.168

Shilev, S., Mitkov, A., Popova, V., Neykova, I., Minev, N., Szulc, W., Yordanov, Y., Yanev, M., 2024. *Fertilization type differentially affects barley grain yield and nutrient content, soil and microbial properties*. Microorganisms, 12, 1447. https://doi.org/10.3390/microorganisms12071447

Terefe, Z., Feyisa, T., Molla, E., Ejigu, W., 2024. *Effects of vermicompost and mineral fertilizers on soil properties, malt barley (Hordeum distichum L.) yield, and economic benefits*. Agrosyst. Geosci. Environ., 7, e20550. https://doi.org/10.1002/agg2.20550

Walkley, A., and Black, I.A., 1934. *An examination of the Degtjareff method for determining soil organic matter*. Soil Sci., 37: 29-38.

Yu, H., Bo, Y., Jie, L., Song, Y., Liu, Y., 2024. *Tree species-dependent effects of afforestation on soil fungal diversity, functional guilds and co-occurrence networks in northern China*. Environ. Res., 263, 120258. https://doi.org/10.1016/j.envres.2024.120258