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Comparative Study of Different Organic Fertilizers on Quinoa Performance in Marginal Soils

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Abstract

Quinoa is gaining attention as a climate-resilient crop suitable for cultivation in marginal soils. This study was piloted at the Postgraduate Agricultural Research Station (PARS), University of Agriculture, Faisalabad, during the Rabi season 2024–25 to estimate the effect of various organic fertilizer combinations on the growth and yield of quinoa under nutrient-deficient conditions. The research was organized in a RCB design with six treatments: Control, Compost (10 t ha^{-1}), Vermicompost (5 t ha^{-1}), Biochar (5 t ha^{-1}), Compost + Vermicompost (5 + 2.5 t ha^{-1}), and Compost + Biochar (5 + 2.5 t ha^{-1}), replicated four times. Results indicated that organic amendments significantly enhanced all measured parameters compared to the control. The maximum plant height (115 cm), leaves plant-1 (28), SPAD value (49), and weight of 1000-seeds (3.6 g) were recorded in the Compost + Vermicompost treatment. Similarly, this treatment resulted in the highest grain yield (2,250 kg ha^{-1}) and biomass yield (7.4 t ha^{-1}), trailed by Compost + Biochar (2,200 kg ha^{-1} grain and 7.1 t ha^{-1} biomass). In contrast, the control treatment yielded only 1,450 kg ha^{-1} grain and 4.8 t ha^{-1} biomass. The enhancement in crop performance can be ascribed to enhanced nutrient availability, microbial activity, and soil physical properties under organic amendment applications. These findings suggest that integrating compost with vermicompost or biochar is a boosting strategy for improving quinoa productivity and soil health in marginal lands, supporting sustainable agriculture.

1. INTRODUCTION

Quinoa has emerged as a hardy crop capable of thriving in marginal soils characterized by low fertility, salinity, and water scarcity (Bazile D,). Its adaptability to harsh environments makes it a promising candidate for sustainable agriculture in regions facing soil degradation and climate change challenges. However, optimizing quinoa production in such conditions necessitates effective soil management strategies (Melo D,). Organic amendments, including compost, biochar, and vermicompost, have garnered attention for their potential to enhance soil properties and crop performance.

Marginal soils often suffer from poor structure, low organic matter content, and limited nutrient availability, which impede plant growth and yield. Organic amendments can ameliorate the limitations of marginal soils by enhancing their physio-biochemical i.e., structure, aeration, porosity and water carrying physiognomies that facilitate better root growth and proliferation. They also upsurge biological activity, OM & nutrient status, thereby creating a more favorable environment for plant development. Additionally, they contribute to the buffering capacity and help stabilize pH and salinity levels of soils. Therefore, they play a vital role in restoring soil fertility and supporting sustainable crop production in degraded and nutrient-deficient soils. For instance, biochar addition has been displayed to increase water holding, cation exchange capacity, and microbial activity, thereby enhancing plant growth under stress environments. In a comprehensive investigation by Abbas et al. (Abbas T,), biochar application improved quinoa's salt forbearance and grain produce in saline-sodic soils by moderating physiological and oxidative strain responses.

Compost, derived from putrefied organic matter, enhances soil with critical nutrients and fosters advantageous microbial communities (Hirich A)- (Rahimi Alashti S,). Its application has been associated with improved quinoa growth and yield, particularly in saline conditions. Similarly, vermicompost, produced through the breakdown of organic waste by earthworms, enhances soil structure, nutrient availability, and microbial diversity (Rahimi Alashti S,)- (Paco-Pérez V). Jabeen and Ahmad (Jabeen N,)reported that vermicompost application amplified quinoa yield and amended soil health indicators.

The effectiveness of these organic amendments can diverge depending on soil type, environmental conditions, and amendment physiognomies (El-Gamal BA,), (Ramzani PMA). For example, the influence of biochar on quinoa yield was additionally pronounced in loam soils compared to sandy loam soils, highlighting the importance of soil texture in amendment efficacy (Abdrabou MR)- (Youssef MA). Moreover, the synergistic effects of combining different organic amendments have been explored. A scientific investigation by Fghire et al. (Fghire R, Wahbi S,)validated that the collective application of compost and vermicompost enhanced quinoa's water status and yield under deficit irrigation.

Despite the growing body of research on organic amendments and quinoa cultivation, comparative studies evaluating the performance of different amendments under marginal soil conditions remain limited. Understanding the relative effectiveness of various organic amendments is crucial for developing site-specific soil management practices that optimize quinoa production. This research investigation aims to fill this information gap by conducting a comparative analysis of compost, biochar, and vermicompost on quinoa growth, yield, and soil health in marginal soils. The findings will inform sustainable agricultural practices and add to food security in expanses with challenging growing conditions.

2. MATERIALS AND METHODS

Experimental Site and Duration

The experiment was conducted at the PARS, UAF, Pakistan (31.41°N, 73.07°E). The study site lies in a semi-arid region with scorching summers and cool winters, and the soil is characterized as sandy clay loam with low organic matter and fertility—typical of marginal conditions. The trial was carried out in the Rabi season of 2024–2025.

Soil Sampling and Analysis

Before sowing, composite soil samples were taken from the top 0–15 cm layer of the experimental field. The air dried samples were strained (2 mm) and examined for initial physico-chemical properties. Parameters assessed included pH & EC, total N, OM, available P&K. These baseline results were used to characterize the marginal status of the soil.

Experiment

The trial was laid out in a tetra-replicated RCB Design. Each plot measured 3.0 m × 3.0 m. The following treatments were applied:

- **T1:** Control (No amendment)
- **T2:** Compost @ 10 t ha^{-1}
- **T3:** Vermicompost @ 5 t ha^{-1}
- **T4:** Biochar @ 5 t ha^{-1}
- **T5:** Compost + Vermicompost (5 t ha^{-1} + 2.5 t ha^{-1})
- **T6:** Compost + Biochar (5 t ha^{-1} + 2.5 t ha^{-1})

Organic amendments were thoroughly incorporated into the soil two weeks before sowing to allow for stabilization and nutrient release.

Crop Establishment and Management

Certified seeds of a commonly grown quinoa variety (‘UAF-Q7’) were obtained from the Department of Agronomy, UAF. Seeds were sown manually in rows spaced @ 0.30 m and plants @ 0.15 m. A basal dose of NPK fertilizer (60:40:30 kg ha^{-1}) was applied uniformly across all treatments to ensure basic nutritional requirements, excluding additional inputs from organic sources. Regular agronomic practices i.e., irrigation, weed and pest control were followed uniformly for all treatments.

Data Collection

Growth and yield parameters i.e., height and leaves of plants, chlorophyll, grain and biomass and 1000- seed weight were recorded at regular intervals and at harvest. These included:

Statistical Analysis

The data were subjected to analysis of variance (ANOVA) using Statistix 10 software. Treatment means were compared using the Least Significant Difference (LSD) test at a 5% probability level. Graphs were prepared using Microsoft Excel and OriginPro.

Results and Discussion

The application of different organic amendments significantly influenced the growth, physiological attributes, and yield performance of quinoa cultivated under marginal soil conditions at PARS, University of Agriculture, Faisalabad.

Plant Height

Substantial variances ($p < 0.05$) were experimental in plant height among treatments (Figure 1). The thoroughgoing plant height (115 cm) was detailed in the Compost + Vermicompost treatment, followed closely by Compost + Biochar (112 cm) and Vermicompost alone (110 cm). In contrast, the Control plot produced the shortest plants (85 cm). The improvement in plant height due to organic amendments may be ascribed to heightened nutrient availability, particularly nitrogen, and improved soil physical properties that favor root development. Vermicompost and compost are rich sources of humic substances and microbial activity, which enhance nutrient uptake and plant growth [21].

Number of Leaves per Plant

Organic amendments had a weighty positive effect on the leaves of a single plant (Figure 1). The maximum leaves (28) was observed in the Compost + Vermicompost treatment, statistically similar to Compost + Biochar (27) and Vermicompost (26). The Control treatment recorded the fewest leaves (18). Increased leaf production in amended treatments can be linked to better nutrient status and improved physiological processes such as photosynthesis. Enhanced leaf growth under organic treatments also reflects the improved water-holding capacity and nutrient cycling promoted by organic matter (Abbas T,).

Chlorophyll Content (SPAD Values)

SPAD readings, indicative of chlorophyll content and nitrogen status, were significantly higher in plots receiving organic amendments. The Compost + Vermicompost treatment achieved the highest SPAD value (49), followed by Compost + Biochar (48) and Vermicompost (46). The Control treatment had the lowest SPAD value (35) (Figure 1). The elevated chlorophyll content under organic treatments is likely due to improved nitrogen availability and micronutrient balance. Biochar's contribution to cation exchange capacity may also enhance nutrient retention and uptake, supporting increased chlorophyll synthesis (Hirich A,), (Paco-Pérez V), (Kizito S,).

1000-Seed Weight

A noteworthy escalation in 1000-seed weight was observed under organic amendments (Figure 1). Compost + Vermicompost produced the heaviest seeds (3.6 g), statistically at par with Compost + Biochar (3.5 g), while the Control had the lowest value (2.5 g). The upturn in seed weight may be attributed to better assimilate partitioning and sustained nutrient supply throughout the crop's reproductive stages. The positive impact of organic inputs on seed development aligns with findings by Jabeen and Ahmad (Hirich A,), who reported increased seed quality under vermicompost treatments.

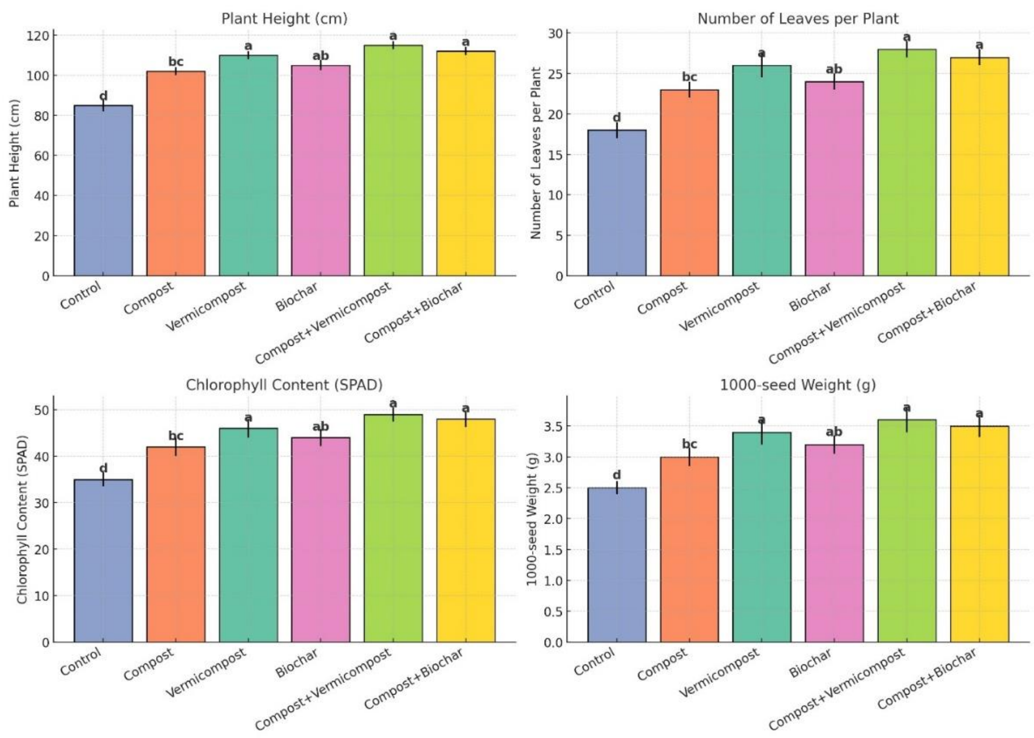

Figure 1: Effect of different organic amendments on plant height (cm), Number of leaves, Chlorophyll content (SPAD) and 1000-seed weight (g) of quinoa under marginal soil conditions.

Grain Yield and Biomass Yield

Grain and biomass yields responded significantly to the addition of organic amendments (Table 1). The maximum grain yield (2,250 kg ha^{-1}) was recorded with the Compost + Vermicompost treatment, followed closely by Compost + Biochar (2,200 kg ha^{-1}). The Control treatment yielded only 1,450 kg ha^{-1}. Similarly, biomass yield was maximized (7.4 t ha^{-1}) with Compost + Vermicompost, significantly higher than the Control (4.8 t ha^{-1}). These results highlight the synergistic benefits of combining organic amendments, which enhance both nutrient supply and soil structure. Compost contributes slow-release nutrients, while vermicompost offers biologically active compounds that promote plant vigor. Biochar, on the other hand, improves soil aeration and moisture retention, creating favorable conditions for root development and nutrient uptake [3] (Abbas T,) (Fghire R, Wahbi S,).

Table 1: Effect of Organic Amendments on Grain Yield and Biomass Yield of Quinoa in Marginal Soils

Treatment	Grain Yield (kg ha^{-1}) ± SE		Biomass Yield (t ha^{-1}) ± SE	
Control	1,450 ± 65	d	4.8 ± 0.25	d
Compost	1,850 ± 72	bc	6.2 ± 0.30	bc
Vermicompost	2,100 ± 80	ab	6.9 ± 0.28	ab
Biochar	1,980 ± 78	bc	6.5 ± 0.26	bc
Compost + Vermicompost	2,250 ± 85	a	7.4 ± 0.30	a
Compost + Biochar	2,200 ± 82	a	7.1 ± 0.32	a

3. CONCLUSION

The superior performance of integrated amendments supports the concept of combining organic sources to maximize nutrient availability, microbial activity, and soil health. These improvements are especially critical in marginal soils, which are typically nutrient-poor and poorly structured. Enhanced yield under organic amendments not only adds to food security but also promotes sustainable soil fertility management, reducing dependence on chemical fertilizers.

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