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Comparative Effects of Two Organic Fertilizers, Inorganic Fertilizer, and Their Integrated Application on Growth and Yield of Common Bean (Phaseolus vulgaris L.) at Kabul Condition

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ABSTRACT :The sustainable management of soil fertility is essential for improving common bean (Phaseolus vulgaris L.) productivity under the semi-arid conditions of Afghanistan. This study evaluated the comparative effects of two organic fertilizers, inorganic fertilizer (NPK), and their integrated application on the growth and yield performance of common bean during the 2025 growing season at the Research Farm of the Faculty of Agriculture, Kabul University. The experiment was arranged in a Randomized Complete Block Design (RCBD) with six fertilizer treatments and three replications. Growth traits, yield components, grain yield, biological yield, and harvest index were analyzed using analysis of variance (ANOVA), and treatment means were separated by Tukey's HSD test at the 5% probability level. Fertilizer treatments significantly influenced most growth and yield parameters. The integrated application of 50% OF-1 + 50% NPK (T5) consistently produced superior plant growth, increased yield components, and achieved the highest grain yield, biological yield, and harvest index compared with the sole application of organic or inorganic fertilizers and the unfertilized control. The improved performance of the integrated treatment was attributed to enhanced nutrient availability and more efficient nutrient utilization throughout the crop growth period. These findings demonstrate that integrated nutrient management is a sustainable and effective strategy for increasing common bean productivity under semi-arid agroecological conditions. Future studies should evaluate long-term effects of integrated nutrient management under diverse agroecological conditions.

KEYWORDS: Common bean, Integrated nutrient management, Organic fertilizer, NPK fertilizer, Grain yield, Sustainable agriculture

1. INTRODUCTION

Common bean (Phaseolus vulgaris L.) is one of the most important grain legumes cultivated for direct human consumption worldwide and plays a significant role in global food security, human nutrition, and sustainable agricultural systems (Broughton et al., 2003; Uebersax et al., 2023). The crop is cultivated across tropical, subtropical, and temperate regions and provides an essential source of dietary protein, energy, and income for millions of smallholder farmers, particularly in developing countries (FAOSTAT, 2023; Uebersax et al., 2023). Due to its adaptability to diverse agroecological environments and its importance in subsistence and commercial farming systems, common bean remains a strategic crop for improving food security and sustainable agricultural production.

Common bean seeds contain approximately 20–25% protein, high-quality carbohydrates, dietary fiber, minerals, vitamins, and various bioactive compounds beneficial for human health (Broughton et al., 2003; Lisciani et al., 2024). Its nutritional composition makes it an affordable alternative source of protein, particularly in regions where access to animal-based protein is limited. Furthermore, the presence of phenolic compounds, flavonoids, and antioxidant components increases its importance as a functional food associated with improved human health and sustainable diets (Lisciani et al., 2024).

Beyond its nutritional value, common bean contributes to sustainable agricultural systems through biological nitrogen fixation and improved nutrient cycling. As a leguminous crop, it forms symbiotic relationships with nitrogen-fixing bacteria, reducing dependence on external nitrogen inputs and contributing to soil fertility improvement (Giller, 2001). The integration of common bean into cropping systems enhances crop diversification, improves soil productivity, and supports environmentally sustainable agricultural practices (Uebersax et al., 2023).

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Despite its importance, common bean productivity remains considerably below its potential in many regions due to multiple constraints, including declining soil fertility, nutrient depletion, low organic matter content, inadequate fertilizer management, drought, and increasing climatic variability (Beebe et al., 2013; Karavidas et al., 2022). Among these limitations, insufficient availability of essential plant nutrients, particularly nitrogen and phosphorus, is one of the major factors restricting vegetative growth, reproductive development, and grain yield formation. These challenges are particularly severe in semi-arid regions, where low rainfall, alkaline soils, and poor soil organic matter frequently limit nutrient availability and crop performance.

In Afghanistan, agricultural productivity is strongly affected by soil fertility degradation, low soil organic carbon, alkaline soil conditions, and inefficient nutrient management practices. Many cultivated soils have limited availability of essential nutrients, especially nitrogen, which restricts crop growth and yield formation. Therefore, improving soil fertility management through efficient and sustainable nutrient strategies is essential for increasing crop productivity and ensuring long-term agricultural sustainability under Afghan agroecological conditions.

Mineral fertilizers have played a major role in increasing agricultural productivity by supplying readily available nutrients required for plant growth and development. However, continuous and excessive dependence on inorganic fertilizers alone may reduce soil quality, decrease soil biological activity, increase nutrient losses, and create environmental concerns (Tilman et al., 2002; Fageria et al., 2011). Therefore, sustainable nutrient management approaches are required to maintain productivity while minimizing negative environmental impacts.

Organic fertilizers provide an important alternative because they improve soil physical, chemical, and biological properties while supplying nutrients gradually throughout the growing season. The application of organic amendments increases soil organic carbon, enhances microbial activity, improves soil aggregation and water-holding capacity, and promotes better root development and nutrient uptake (Chen et al., 2004; Nardi et al., 2002; Diacono & Montemurro, 2010). However, sole application of organic fertilizers may not always provide sufficient nutrients during critical crop growth stages because nutrient release depends on decomposition rate and environmental conditions (Fageria et al., 2011).

Integrated Nutrient Management (INM), combining organic amendments with mineral fertilizers, has therefore emerged as an effective strategy to overcome the limitations of individual fertilizer sources. This approach improves nutrient-use efficiency by combining rapid nutrient availability from mineral fertilizers with the long-term soil improvement effects of organic inputs (Vanlauwe et al., 2010; Zhang et al., 2012). Integrated fertilization enhances nutrient synchronization with crop demand, improves soil fertility, increases biomass accumulation, and promotes higher grain yield compared with sole application of organic or inorganic fertilizers (Fixen et al., 2015).

Recent studies have confirmed the benefits of integrated nutrient management in common bean production. Karavidas et al. (2022) reported that balanced nutrient management significantly improves vegetative growth, yield components, grain yield, and quality characteristics of common bean across different environments. Similarly, integrated application of organic and mineral fertilizers has been shown to improve nutrient availability, soil fertility, and crop productivity compared with the use of individual fertilizer sources (Vanlauwe et al., 2010; Zhang et al., 2012).

Although considerable research has investigated integrated nutrient management, limited information is available regarding the comparative performance of different organic fertilizers combined with mineral fertilizers under semi-arid alkaline soil conditions. In particular, scientific evidence regarding the effectiveness of different organic fertilizer sources for improving common bean productivity in Afghanistan remains scarce. Identifying suitable combinations of organic and inorganic nutrient sources is therefore essential for developing sustainable fertilizer recommendations adapted to local environmental conditions.

Therefore, the present study was conducted to evaluate the comparative effects of two organic fertilizers, inorganic fertilizer (NPK), and their integrated application on growth characteristics, yield components, biological yield, grain yield, and harvest index of common bean (Phaseolus vulgaris L.) under the semi-arid conditions of Kabul, Afghanistan. The findings of this study provide valuable information for developing sustainable nutrient management strategies aimed at improving common bean productivity while maintaining long-term soil fertility.

2. MATERIALS AND METHODS

2.1 Study Area

The field experiment was conducted during the 2025 growing season (10 May to 30 August 2025) at the Research Farm of the Department of Agronomy, Faculty of Agriculture, Kabul University, Afghanistan. The experimental site is located at approximately 34°31′15″ N latitude and 69°08′24″ E longitude, with an elevation of about 1,800 m above sea level. Kabul has a semi-arid continental climate characterized by cold winters, warm summers, and low annual precipitation averaging approximately 310–312 mm, most of which occurs during spring. Summer rainfall is generally negligible, making irrigation essential for crop production.

2.2 Soil Sampling and Analysis

Prior to land preparation, composite soil samples were collected randomly from the 0–25 cm soil depth using a hand auger. Samples were air-dried under laboratory conditions, crushed gently, and passed through a 2-mm sieve before laboratory analysis.

The soil was analyzed for selected physical and chemical properties following standard analytical procedures. Soil texture was determined by the hydrometer method, soil pH using a pH meter (1:5 soil-water suspension), electrical conductivity (EC) by EC meter (1:10 extract), available nitrogen using the Kjeldahl method, available phosphorus by the Olsen method, available potassium and sodium using a flame photometer, organic carbon by the Walkley–Black method, and calcium carbonate through titration.

The experimental soil was classified as loam with a slightly alkaline reaction (pH 8.2), low organic carbon content (0.34%), low organic matter (0.57%), and relatively low available nitrogen, indicating poor soil fertility that required external nutrient supplementation.

Table 1. Physical and chemical properties of the experimental soil before planting

Property	Value
Sand (%)	49.08
Silt (%)	31.20
Clay (%)	19.20
Textural class	Loam
Bulk density (g cm^{-3})	1.42
Soil pH	8.20
EC (dS m^{-1})	0.133
Available N (kg ha^{-1})	42.38
Available P (mg 100 g^{-1} soil)	73.60
Available K (ppm)	181.30
Exchangeable Na (ppm)	121.50
Available Ca (ppm)	1379.03
$CaCO_3$ (%)	22.50
Organic carbon (%)	0.34
Organic matter (%)	0.57

Source: *Agricultural Research Institute of Afghanistan (ARIA), Soil Laboratory (2025).*

2.3 Characteristics of Organic Fertilizers

Two commercially produced organic fertilizers were evaluated in the present study. Laboratory analysis indicated that both fertilizers possessed similar physicochemical properties, differing mainly in their macronutrient concentrations. Organic Fertilizer-2 (OF-2) contained higher concentrations of nitrogen, phosphorus, and potassium than Organic Fertilizer-1 (OF-1).

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Table 2. Chemical characteristics of the organic fertilizers used in the experiment

Property	OF-1	OF-2
Total Nitrogen (%)	3.50	5.00
Available Phosphorus (P_2O_5, %)	1.98	3.00
Available Potassium (K_2O, %)	2.65	5.00
Zinc (%)	0.041	0.041
Copper (ppm)	56.28	56.28
Organic Carbon (%)	25.12	25.12
Organic Matter (%)	49.23	49.23
Humic Acid (%)	7.92	7.92
Fulvic Acid (%)	3.60	3.60
pH	8.37	8.37
Moisture (%)	21.25	21.25
Lead (Pb, ppm)	38.22	38.22
Nickel (Ni, ppm)	65.79	65.79
Cadmium (Cd, ppm)	1.29	1.29
Chromium (Cr, ppm)	49.52	49.52

Source: *Laboratory Analysis Report, Organic Fertilizer Production Company (2024).*

2.4 Experimental Design and Treatments

The experiment was arranged in a Randomized Complete Block Design (RCBD) consisting of six fertilizer treatments with three replications, resulting in a total of eighteen experimental plots.

Each plot measured 4.0 m², comprising four rows spaced 40 cm apart with 20 cm plant spacing within rows. The total experimental area covered approximately 144 m².

Table 3. Fertilizer treatments applied in the experiment

Treatment	**Description**
T1	Control (no fertilizer)
T2	NPK (100:100:60): 44g urea + 88g DAP + 48g SoP & 44g urea top-dressing
T3	OF-1 (2000 kg/ha): 800g per plot
T4	OF-2 (1000 kg/ha): 400g per plot
T5	50% OF-1 + 50% NPK: 400g OF-1 + 22g urea + 44g DAP + 24g SoP & 22g urea top-dressing
T6	50% OF-2 + 50% NPK: 200g OF-2 + 22g urea + 44g DAP + 24g SoP & 22g urea top-dressing

2.5 Crop Establishment and Field Management

The experimental field was ploughed, harrowed, and leveled before planting to obtain a fine seedbed. Common bean seeds were sown manually on 3 May 2025 at a depth of 2–3 cm, maintaining 40 cm row spacing and 20 cm spacing between plants. Approximately 39 plants were established per plot.

Organic fertilizers were incorporated into the soil before sowing, whereas phosphorus and potassium fertilizers were applied as basal dressing. Nitrogen fertilizer was applied in two equal splits, with half applied at planting and the remainder as top-dressing during vegetative growth.

Weed control was performed manually at monthly intervals to minimize crop–weed competition. Irrigation and other agronomic practices were uniformly maintained across all treatments throughout the growing season.

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2.6 Data Collection

Seven plants were randomly selected from the two central rows of each experimental plot and permanently tagged for recording growth and yield observations.

The following agronomic parameters were measured:

Plant height (cm)
Leaf length (cm)
Number of leaves per plant
Number of branches per plant
Number of pods per plant
Pod length (cm)
Number of seeds per pod
Hundred-seed weight (g)
Biological yield (g $plot^{-1}$)
Grain yield (g $plot^{-1}$)
Harvest index (%)

Plant height was measured from the soil surface to the terminal bud using a graduated ruler. Yield components were recorded at physiological maturity, whereas biological and grain yields were determined after harvesting and drying the crop to approximately 12% seed moisture content.

2.7 Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) using the Statistical Tool for Agricultural Research STAR version 2.0.1. Combined analysis across the two experimental sites was performed to determine the effects of treatments, sites, and treatment × site interactions. Treatment means were separated using the Tukey HSD test at the 5% probability level ($P \leq 0.05$). Statistical significance was declared at $P < 0.05$, while highly significant differences were considered at $P < 0.01$ and $P < 0.001$.

3. RESULTS

3.1 Combined Analysis of Variance

The combined analysis of variance (ANOVA) across the two experimental sites revealed that fertilizer treatments significantly affected almost all measured growth and yield traits of common bean (Table 4). Plant height, leaf length, number of leaves per plant, number of branches per plant, number of pods per plant, pod length, biological yield, grain yield, and harvest index were highly significant ($P < 0.001$). Seed number per pod ($P < 0.01$) and 100-seed weight ($P < 0.05$) were also significantly influenced by fertilizer treatments.

The main effect of experimental sites was generally non-significant for most measured parameters, except for plant height, which differed significantly between the two experimental sites. Likewise, treatment × site interactions were non-significant for most growth and yield attributes, indicating that fertilizer treatments produced relatively consistent responses across the two locations. However, harvest index showed a significant treatment × site interaction ($P < 0.05$), suggesting slight differences in assimilate partitioning between environments.

The coefficients of variation remained within acceptable limits, indicating satisfactory experimental precision and reliability of the obtained data.

Table 4. Combined analysis of variance (ANOVA) for growth and yield traits of common bean across two experimental sites

Source of Variation	df	PH	LL	NLP	NBP	NPP	PL	SPP	HSW	BY	GY	HI
Years Sites	1	0.442***	0.389 ns	2.834ns	0.004ns	0.001 ns	0.002 ns	0.504 ns	128.822ns	85.563ns	0.585ns	4.175ns

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Replication (Years)	2	0.065ns	0.352 ns	0.135ns	0.080ns	0.547 *	0.371 ns	0.106 ns	39.092 ns	1582.543 ns	84.456*	0.349ns
Treatments	5	148.285 ***	5.103 ***	60.204***	32.629 ***	7.429 ***	5.873 ***	1.284 **	200.513*	93698.503***	3239.692***	32.198***
Years × Treatments	5	0.089ns	0.227 ns	17.794ns	0.020ns	0.008 ns	0.020 ns	0.056 ns	100.811ns	90.285ns	0.277ns	2.382*
Error	10	2.486	0.213	3.168	0.456	0.098	0.247	0.204	38.656	2544.124	13.528	0.638

Note: df = degrees of freedom; PH = plant height; LL = leaf length; NLP = number of leaves per plant; NBP = number of branches per plant; NPP = number of pods per plant; PL = pod length; SPP = seeds per pod; HSW = hundred-seed weight; BY = biological yield; GY = grain yield; HI = harvest index. ns = non-significant ($P > 0.05$); * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

3.2 Effect of fertilizer treatments on growth, yield components, and yield performance

Mean comparisons indicated significant differences among fertilizer treatments for all measured growth and yield parameters (Table 5).

Plant height ranged from 28.48 cm under the unfertilized control (T1) to 42.32 cm under the recommended NPK treatment (T2). However, integrated nutrient management (T5) also produced comparatively taller plants (41.12 cm) and did not differ significantly from T2.

Leaf length was significantly increased by fertilizer application, with the maximum value (13.03 cm) recorded under T5, whereas the shortest leaves (10.35 cm) were observed in the control treatment.

The highest number of leaves per plant (44.00) and branches per plant (10.42) were obtained from T5, followed closely by T3 and T2. In contrast, plants grown without fertilizer produced significantly fewer leaves and branches.

Regarding reproductive development, the integrated treatment (T5) recorded the greatest number of pods per plant (14.09), longest pod length (14.60 cm), and highest number of seeds per pod (5.87). These values were significantly superior to those of the control treatment.

Hundred-seed weight was also significantly affected by fertilizer management. The highest seed weight (41.77 g) was recorded under T3, whereas the lowest value (26.42 g) was observed under T4.

Biological yield increased substantially following fertilizer application. The integrated treatment T5 produced the greatest biological yield (1576.92 g $plot^{-1}$), while the control recorded only 1223.93 g $plot^{-1}$.

Similarly, grain yield was markedly improved by nutrient management. The highest grain yield (482.01 g $plot^{-1}$) was achieved with T5, followed by T3 (479.40 g $plot^{-1}$) and T6 (465.37 g $plot^{-1}$). The unfertilized control consistently produced the lowest grain yield (422.73 g $plot^{-1}$).

Harvest index followed a similar trend, with the highest value (36.76%) obtained under T5, indicating more efficient partitioning of assimilates toward grain production.

Table 5. Effect of nutrient management treatments on growth and yield traits of common bean (combined mean of two experimental sites)

Treatments	PH (cm)	LL (cm)	NLP	NBP	NPP	PL (cm)	SPP	HSW (g)	BY (g $plot^{-1}$)	GY (g $plot^{-1}$)	HI (%)
T1 (Control)	28.48d	10.35c	34.74c	4.16d	11.29c	12.10c	4.50b	35.15c	1223.93d	422.73d	30.85d
T2 (100% NPK)	42.32a	12.51a	41.77b	9.89ab	13.15ab	12.70bc	5.09ab	39.37b	1524.57b	459.02c	36.57a
T3 (100% OF-1)	38.78bc	11.80b	41.82ab	10.05a	13.58a	14.43a	5.25a	41.77a	1507.57bc	479.40a	33.77bc

T4 (100% OF-2)	37.69c	11.44b	41.64b	8.49c	11.82bc	13.50b	4.89ab	26.42d	1495.22c	438.87b	32.38c
T5 (50% OF-1 + 50% NPK)	41.12ab	13.03a	44.00a	10.42a	14.09a	14.60a	5.87a	40.80a	1576.92a	482.01a	36.76a
T6 (50% OF-2 + 50% NPK)	39.97b	11.90b	40.03b	9.25b	11.99bc	12.95bc	5.42ab	40.05ab	1503.15bc	465.37b	34.30b

Note: PH = plant height; LL = leaf length; NLP = number of leaves per plant; NBP = number of branches per plant; NPP = number of pods per plant; PL = pod length; SPP = seeds per pod; HSW = hundred-seed weight; BY = biological yield; GY = grain yield; HI = harvest index. Means followed by the same letter within a column are not significantly different according to Tukey's honestly significant difference (HSD) test at P ≤ 0.05.

3.3 Growth attributes of common bean

The fertilizer treatments significantly affected the vegetative growth of common bean across both experimental sites. Plant height, number of leaves, leaf length, and number of branches showed significant differences among treatments, with the integrated application of organic fertilizer and mineral fertilizer (T5) consistently producing the highest values for most growth traits. In contrast, the control treatment (T1) resulted in the lowest growth performance at both locations. Overall, integrated nutrient management promoted superior vegetative development compared with the sole application of organic or inorganic fertilizers.

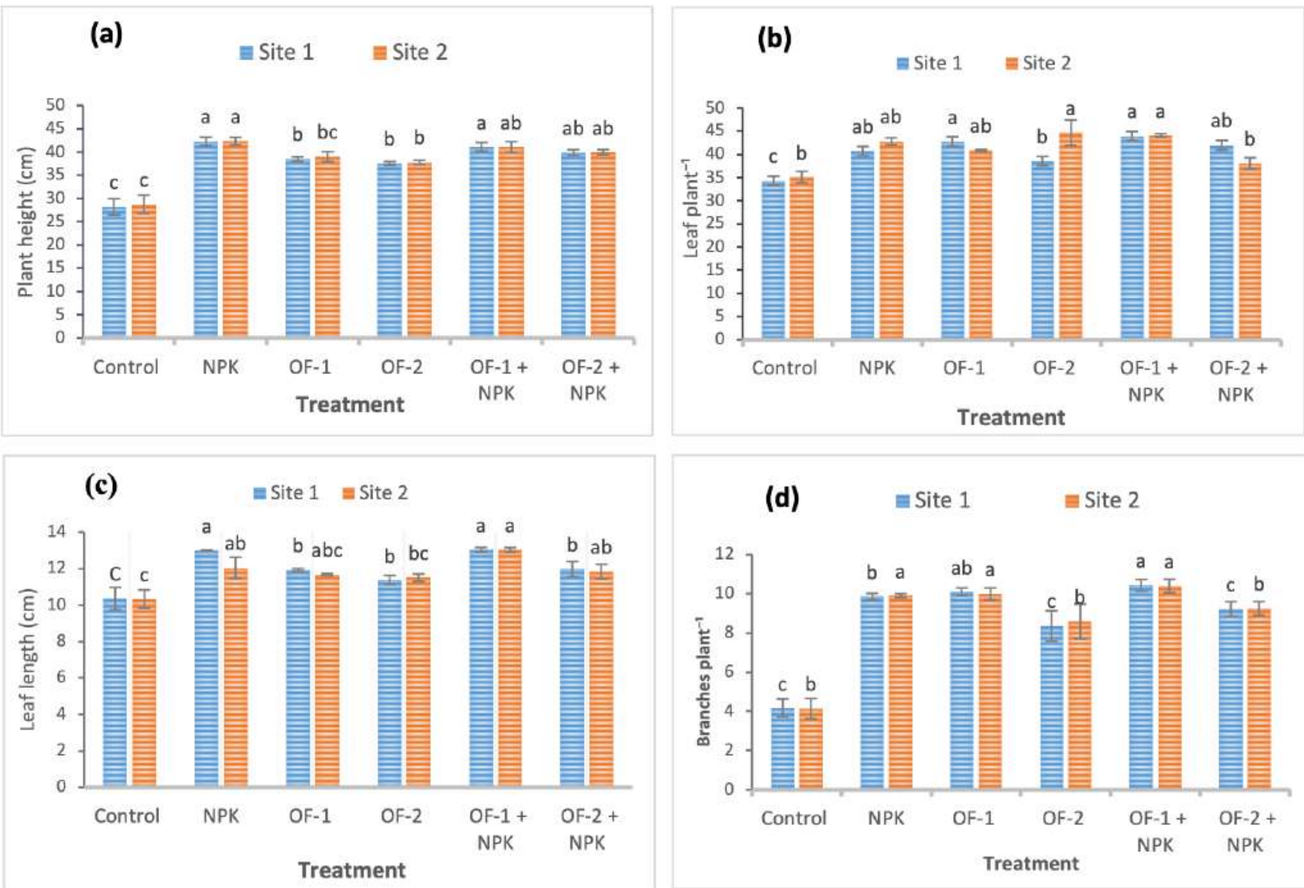

Figure 1. Effect of fertilizer treatments on vegetative growth traits of common bean across two experimental sites. (a) Plant height, (b) number of leaves per plant, (c) leaf length, and (d) number of branches per plant. Different letters indicate significant differences among treatments according to Tukey's HSD test at P ≤ 0.05.

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3.4 Yield components

Significant treatment effects were observed for the major yield components of common bean. The number of pods per plant, pod length, and 100-seed weight increased significantly under integrated fertilizer application, particularly in treatment T5. The number of seeds per pod showed significant differences at the first experimental site but was not significantly affected at the second site. Nevertheless, the integrated fertilizer treatment generally produced the highest values for reproductive traits, whereas the control treatment consistently recorded the lowest performance.

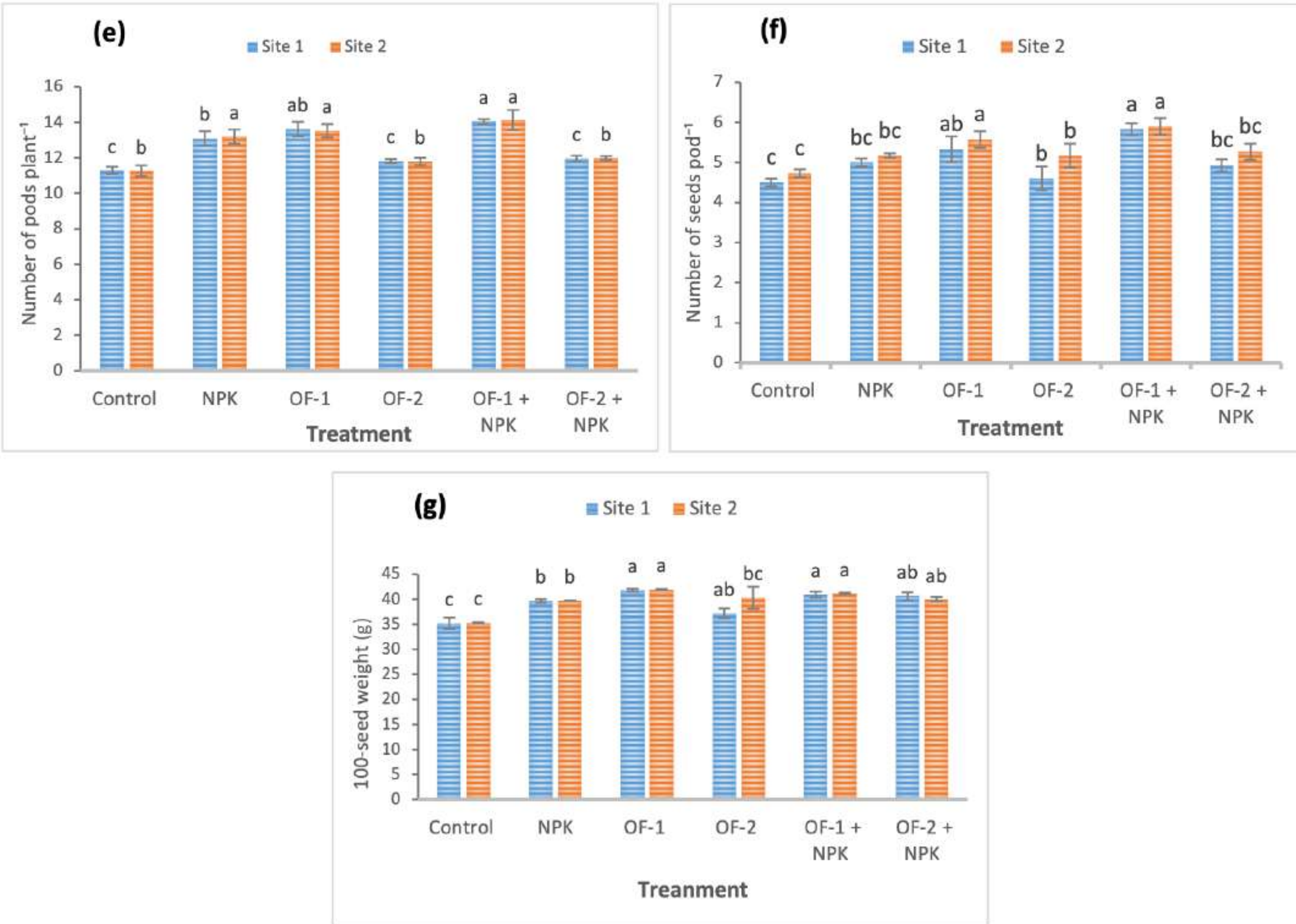

Figure 2. Effect of fertilizer treatments on yield components of common bean across two experimental sites. (e) Number of pods per plant, (f) number of seeds per pod, and (g) 100-seed weight. Different letters indicate significant differences among treatments according to Tukey's HSD test at $P \leq 0.05$.

3.5 Yield performance

Biological yield, grain yield per plot, and harvest index were significantly influenced by fertilizer management at both experimental sites. The highest biological yield and grain yield were obtained from treatment T5, followed by T3, T6, and T2, while the control treatment produced the lowest values. Harvest index also showed significant variation among treatments, indicating that integrated nutrient management improved biomass production and yield efficiency under field conditions.

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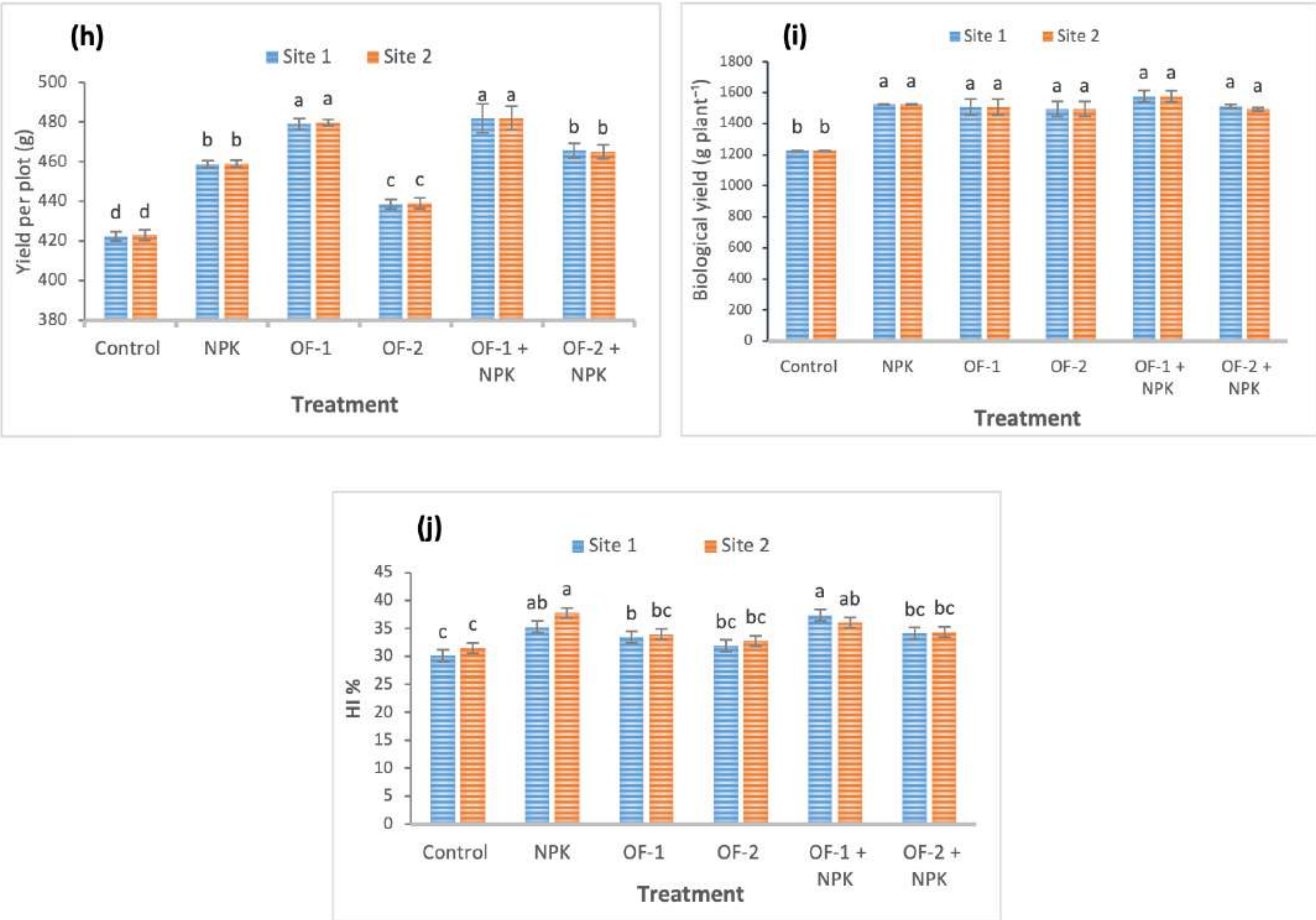

Figure 3. Effect of fertilizer treatments on yield performance of common bean across two experimental sites. (a) Biological yield, (b) grain yield per plot, and (c) harvest index. Different letters indicate significant differences among treatments according to Tukey's HSD test at $P \leq 0.05$.

4. DISCUSSION

4.1 Effect of Nutrient Management on Vegetative Growth

The present study demonstrated that nutrient management significantly improved vegetative growth characteristics of common bean, including plant height, leaf length, number of leaves, and branches (Tables 4 and 5). Combined ANOVA revealed highly significant treatment effects ($P < 0.001$) for all vegetative traits, whereas site × treatment interactions were non-significant, indicating consistent fertilizer responses across both experimental sites.

Among fertilizer treatments, the integrated application of 50% Organic Fertilizer-1 + 50% NPK (T5) produced the highest leaf length (13.03 cm), number of leaves (44 plant^{-1}), and number of branches (10.42 plant^{-1}), while maximum plant height was recorded under recommended NPK application (42.32 cm). The superior vegetative performance under integrated nutrient management may be attributed to the complementary effects of organic and mineral nutrient sources. Mineral fertilizers provide rapidly available nitrogen, phosphorus, and potassium required for early plant development, chlorophyll formation, protein synthesis, and cell division. In contrast, organic fertilizers ensure gradual nutrient release while improving soil aggregation, moisture retention, microbial activity, and root proliferation, thereby enhancing nutrient use efficiency.

These findings agree with Fageria et al. (2011), who reported that balanced nutrient supply improves photosynthetic efficiency and vegetative growth of grain legumes. Similarly, Chen et al. (2004) and Nardi et al. (2002) demonstrated that humic substances from organic amendments stimulate root development, nutrient uptake, enzymatic activity, and plant metabolism. The lower vegetative performance under the control treatment indicates that the experimental soils, characterized by limited fertility and low nutrient availability, could not provide sufficient resources for optimum crop growth. This finding is particularly important under Afghan agricultural conditions, where alkaline soils, low organic matter content, and nutrient depletion are major constraints limiting common bean productivity.

4.2 Effect of Nutrient Management on Yield Components

Yield components showed significant responses to fertilizer management, highlighting the importance of balanced nutrient availability during reproductive development. The integrated treatment (T5) produced the highest number of pods per plant (14.09), longest pods (14.60 cm), and greatest number of seeds per pod (5.87), indicating improved reproductive efficiency and enhanced yield potential.

The improvement in yield components under integrated fertilization can be explained by improved flowering, reduced flower abortion, enhanced pollen development, and efficient translocation of assimilates from source tissues toward developing pods and seeds. Continuous nutrient availability from combined organic and mineral sources likely maintained photosynthetic activity during pod formation and grain filling, resulting in improved sink development.

These results are consistent with Karavidas et al. (2022), who concluded that balanced fertilization significantly improves pod number, seed setting, and grain quality in common bean. Similarly, Selim (2020) reported that integrated nutrient management prolongs nutrient availability during reproductive stages, enhancing pod development and seed filling. The highest 100-seed weight observed under Organic Fertilizer-1 alone (T3; 41.77 g) suggests that gradual nutrient mineralization from organic amendments may have favored prolonged assimilate accumulation and grain filling, supporting the findings of Habibi et al. (2025).

4.3 Effect of Nutrient Management on Biological Yield and Grain Yield

Biological yield and grain yield were strongly influenced by fertilizer treatments. The integrated treatment (T5) recorded the highest biological yield (1576.92 g $plot^{-1}$) and grain yield (482.01 g $plot^{-1}$), whereas the control treatment showed the lowest biomass and grain production.

The superior performance of integrated nutrient management can be attributed to the synergistic interaction between organic and inorganic fertilizer sources. Mineral fertilizers rapidly satisfy crop nutrient requirements during early growth stages, whereas organic fertilizers provide sustained nutrient release and improve soil physical and biological properties. This balanced nutrient supply promotes greater leaf area development, stronger root systems, higher photosynthetic capacity, and improved nutrient uptake efficiency throughout the growing season.

The present findings are in agreement with Habibi et al. (2025), who reported that combined organic and mineral fertilization significantly enhanced biomass accumulation, chlorophyll concentration, nutrient uptake, and grain yield of common bean under alkaline soils. Similar observations were reported by Baghdadi et al. (2018) and Fageria et al. (2011), who emphasized that integrated nutrient management generally surpasses sole organic or mineral fertilization due to improved nutrient synchronization and enhanced soil fertility.

The lower grain yield under sole NPK application compared with T5 suggests that mineral fertilizers alone may not sufficiently improve soil biological processes and long-term nutrient availability. Conversely, although organic fertilizers improved several yield components, their slower nutrient release may limit early crop growth when compared with integrated fertilization.

4.4 Harvest Index and Dry Matter Partitioning

Harvest index represents the efficiency of biomass conversion into economic yield and is an important indicator of crop productivity. In this study, harvest index significantly differed among treatments, with the highest values observed under T5 (36.76%) and T2 (36.57%). These results indicate that integrated nutrient management enhanced not only biomass production but also the partitioning of assimilates toward grain formation.

The improvement in harvest index under integrated fertilization may result from improved source–sink relationships through balanced nutrient availability. Nitrogen promotes canopy development and photosynthetic capacity, phosphorus supports energy transfer and reproductive development, while potassium regulates carbohydrate movement toward developing grains. Organic amendments further improve nutrient retention and microbial activity, supporting nutrient availability during grain filling.

These findings corroborate those of Nardi et al. (2002) and Selim (2020), who demonstrated that integrated nutrient management improves nutrient mobilization, dry matter partitioning, and physiological efficiency, resulting in enhanced harvest index and grain productivity.

4.5 Stability of Fertilizer Response Across Experimental Sites

Combined analysis of variance showed non-significant treatment × site interactions for most measured traits, except harvest index, indicating that fertilizer treatments performed consistently across both experimental locations. This stability demonstrates the reliability of integrated nutrient management under different field conditions similar to those represented in this study.

The absence of significant interaction for most traits suggests that environmental variation between the two sites was insufficient to alter treatment ranking. Stable fertilizer performance is highly desirable in agronomic research because it increases the reliability and practical applicability of nutrient recommendations. Similar conclusions were reported by Karavidas et al. (2022), who noted that balanced fertilization practices generally produce consistent improvements in common bean productivity across different environments.

Overall, the present study confirms that integrating organic fertilizer with mineral NPK fertilizer improves vegetative growth, yield components, biomass accumulation, grain yield, and harvest efficiency more effectively than applying either fertilizer source alone. These findings provide strong evidence that integrated nutrient management represents a sustainable strategy for improving common bean production under alkaline and nutrient-deficient soils, particularly in the agricultural conditions of Afghanistan.

5. CONCLUSION

The present study demonstrated that nutrient management strategies significantly influenced growth characteristics, yield components, biomass production, and grain productivity of common bean (Phaseolus vulgaris L.) under Kabul agro-ecological conditions. The combined analysis of variance across two experimental sites confirmed that fertilizer treatments had significant effects on most evaluated traits, whereas site × treatment interactions were generally non-significant, indicating consistency and reliability of treatment responses across environments.

Among the evaluated nutrient management practices, the integrated application of organic fertilizer type-1 with mineral NPK fertilizer (T5: 50% OF-1 + 50% NPK) showed the most superior performance. This treatment resulted in the highest plant growth attributes, including number of leaves, branching, and reproductive development. Furthermore, T5 produced the maximum biological yield (1576.92 g plot^{-1}), grain yield (482.01 g plot^{-1}), and harvest index (36.76%), demonstrating improved nutrient utilization efficiency and better assimilate partitioning toward economic yield.

The positive response of common bean to integrated nutrient management can be attributed to the complementary effects of organic and inorganic nutrient sources. Mineral fertilizers provide rapidly available nutrients, particularly nitrogen, phosphorus, and potassium, required during critical growth stages, while organic fertilizers improve soil physical properties, microbial activity, nutrient retention capacity, and gradual nutrient release.

The application of sole organic fertilizers also improved crop performance compared with the unfertilized control, indicating the beneficial role of organic amendments in improving soil fertility. However, the integrated approach was more effective than individual fertilizer sources because it provided a balanced and continuous nutrient supply throughout the crop growth period.

The control treatment recorded the lowest values for almost all measured parameters, confirming that nutrient deficiency was a major limiting factor for common bean productivity in the studied soils characterized by alkaline pH and low organic carbon content.

Overall, the results suggest that partial substitution of mineral fertilizers with organic fertilizers through integrated nutrient management is an efficient and sustainable strategy for increasing common bean productivity while improving long-term soil fertility under semi-arid conditions.

The findings provide practical implications for sustainable bean production under semi-arid environments.

6. RECOMMENDATIONS

Based on the findings of this study, the following recommendations are proposed:

- ✓ Integrated nutrient management (50% OF-1 + 50% NPK) is recommended as an effective fertilizer strategy for improving common bean growth and yield under Kabul conditions.

- ✓ Farmers should avoid continuous cultivation without nutrient replacement because nutrient depletion can substantially reduce crop productivity, especially in soils with low organic matter content.
- ✓ Organic fertilizer application should be encouraged because it improves soil quality, increases nutrient availability, and contributes to sustainable agricultural production.
- ✓ Further studies should evaluate the long-term effects of repeated organic fertilizer application on soil chemical properties, microbial activity, and crop productivity.
- ✓ Multi-location experiments covering different agro-ecological zones of Afghanistan are recommended to validate the adaptability and economic feasibility of integrated nutrient management practices.
- ✓ Economic analysis including fertilizer cost, benefit–cost ratio, and farmers' acceptance should be incorporated in future research to determine the most profitable fertilizer strategy.

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8. CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this research article.

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