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Synergistic Effects of Organic and Potassium Fertilization on Soil Properties and Pinto Bean Performance

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Abstract

Low organic matter in many Iranian soils leads to soil structural degradation and reduced crop productivity. Applying chicken manure offers a cost-effective organic amendment that improves soil quality by supplying organic matter and nutrients through gradual release. This study aimed to evaluate the effects of chicken manure and potassium fertilizer on pinto bean yield and determine soil physical and chemical properties under field conditions. The experiment was arranged in a split-plot design within a randomized complete block design with three replications. Chicken manure was applied to main plots at four rates (0, 5, 10, and 15 t ha^{-1}), while potassium fertilizer, supplied as potassium sulfate (K_2O), was applied to sub-plots at four levels (0, 100, 175, and 250 kg ha^{-1}). Yield components of pinto bean and soil physical and chemical properties were measured. The results indicated that both chicken manure and potassium fertilizer significantly increased pinto bean seed yield, with the highest yield obtained at 15 t ha^{-1} of chicken manure combined with 250 kg ha^{-1} of potassium fertilizer. The application of both inputs also enhanced yield components, including number of pods per plant, harvest index, and seed protein content. Chicken manure significantly improved soil physical properties by increasing water infiltration rate, saturated moisture, and total porosity, while reducing bulk density. It also enhanced soil chemical properties by increasing electrical conductivity, soil organic carbon, and available phosphorus, as well as lowering soil pH. In contrast, potassium fertilizer primarily increased soil electrical conductivity and reduced the final infiltration rate. The results demonstrate that chicken manure substantially improves soil quality and pinto bean productivity. The integration of organic and chemical fertilizers can be considered an effective and sustainable nutrient management strategy for improving soil fertility in low-organic-matter soils.

INTRODUCTION

Agricultural systems have traditionally relied on chemical fertilizers as a primary source of essential plant nutrients to maximize land productivity and maintain soil fertility. Nitrogen, phosphorus, and potassium play fundamental roles in plant metabolic processes, and their application is known to enhance crop growth and yield (Asadu et al., 2024). Among these nutrients, potassium is particularly important due to its role in enzyme activation, regulation of plant water relations and stomatal conductance, photosynthesis, assimilate transport, and plant tolerance to abiotic and biotic stresses such as drought, salinity, and diseases (Sardans and Peñuelas, 2021). However, despite their agronomic benefits, the long-term and unbalanced use of chemical fertilizers has led to significant concerns regarding soil degradation and environmental sustainability. Continuous reliance on chemical fertilizers has been associated with declining

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soil organic carbon, deterioration of soil structure, and increased nutrient losses through leaching and volatilization, ultimately contributing to environmental pollution and reduced nutrient use efficiency (Yuan et al., 2025). These challenges are particularly critical in arid and semi-arid regions, where soils are inherently low in organic matter and more vulnerable to structural degradation and moisture limitations. In response to these limitations, increasing attention has been directed toward organic fertilizers as sustainable alternatives or complements to chemical inputs. Organic amendments, such as animal manure, compost, and green manure, have been shown to improve soil structure, enhance aggregate stability, increase water infiltration and retention, and reduce soil erodibility. Organic matter plays a crucial role in regulating soil physical, chemical, and biological functions by improving pore distribution and enhancing microbial activity (Song, 2025). Among organic amendments, chicken manure has attracted considerable interest due to its high nutrient content and rapid mineralization rate. It is particularly rich in nitrogen, potassium, calcium, and organic compounds, with nitrogen largely present in readily available forms such as uric acid (Verner, 2023). Previous studies have demonstrated the positive effects of chicken manure on soil properties and crop productivity (Agbede and Oyewumi, 2022; Mpanga et al., 2021). Although both chemical and organic fertilizers individually contribute to crop production, their integrated use has been increasingly proposed as a strategy to enhance nutrient efficiency while maintaining long-term soil health. Integrated nutrient management can improve nutrient availability, optimize soil physical conditions, and mitigate environmental impacts associated with excessive chemical fertilizer use. Leguminous crops, such as pinto bean (*Phaseolus vulgaris* L.), play a critical role in sustainable agriculture due to their ability to fix atmospheric nitrogen and their high nutritional value. Beans contain approximately 25% protein and represent a major source of plant-based protein worldwide. Improving soil fertility and structure is, therefore, essential not only for increasing yield but also for enhancing the nutritional quality of these crops. Despite extensive research on organic amendments and potassium fertilization, most previous studies have evaluated these inputs independently or under controlled conditions, with limited attention to their interactive effects under field conditions, particularly in semi-arid environments. Moreover, there remains a lack of integrated assessments that simultaneously consider crop productivity alongside changes in soil physical and chemical properties. This gap limits the development of practical nutrient management strategies suitable for water-limited agroecosystems. Therefore, the novelty of this study lies in evaluating the combined effects of chicken manure and potassium fertilizer under field conditions in a semi-arid region, with a dual focus on both crop performance and soil property dynamics. By addressing this gap, the study provides a more comprehensive understanding of how integrated fertilization strategies can enhance sustainability and resilience in cropping systems. Accordingly, the objective of this study was to evaluate the effects of various rates of chicken manure and potassium fertilizer on pinto bean yield and yield components, as well as on selected physical and chemical properties of soil under field conditions. This research aimed to provide practical insights into integrated nutrient management strategies for improving soil quality and crop productivity in semi-arid agroecosystems.

MATERIALS AND METHODS

This study was conducted in the agricultural areas surrounding Semnan City (38°09′17″ N, 44°49′22″ E) at an elevation of 1,083 m above sea level during the first half of March 2021. Based on available meteorological data, the region is characterized by a semi-arid climate with dry summers. According to records from the Semnan Synoptic Meteorological Station, the majority of annual precipitation occurs during the first three months of the year.

Prior to treatment application, soil samples were collected from multiple locations at a depth of 0–30 cm. The samples were completely mixed and analyzed in the laboratory to determine selected physical and chemical soil properties (Table 1). Available phosphorus was determined using the Olsen method, while available potassium was extracted with ammonium acetate and quantified using a flame photometer (Page et al., 1992). Soil pH and electrical conductivity (EC) were measured using a pH meter and an EC meter, respectively. Soil organic carbon content was determined following the Walkley and Black method (1934). Soil texture was assessed using the hydrometric method, saturated moisture content was measured using the oven-drying method, and bulk density was determined using the Klokheh method (Page et al., 1992).

Table 1. Characteristics of the experiment soil before planting

Category	Parameter	Unit	Value
Physical	Bulk density	g cm^{-3}	1.35
Physical	Soil texture	—	Loam
Physical	Saturated moisture	%	23.50
Chemical	pH	—	7.80
Chemical	EC	dS m^{-1}	1.80
Chemical	Organic carbon	%	0.17
Chemical	Available phosphorus	ppm	2.40
Chemical	Available potassium	ppm	250.00
Biological	Microbial biomass carbon	mg kg^{-1}	Not measured
Biological	Soil respiration	mg CO_2 kg^{-1} day^{-1}	Not measured
Biological	Enzyme activity (dehydrogenase)	—	Not measured

The experiment was arranged in a split-plot design within a randomized complete block design (RCBD) with two experimental factors and three replications. Chicken manure was assigned as the main-plot factor at four application rates (0, 5, 10, and 15 t ha^{-1}), while potassium fertilizer, applied as potassium sulfate (K_2O), was allocated to the sub-plots at four levels (0, 100, 175, and 250 kg ha^{-1}). The chemical and decomposition characteristics of the chicken manure (70% decomposed) used in the experiment are presented in Table 2.

Following primary tillage to ensure relatively uniform soil conditions, land preparation and plot layout were conducted. Based on the applied treatments, 18 experimental plots were established, each measuring 2 × 2 m. Each plot consisted of seven crop rows spaced 50 cm apart, with an intra-row plant spacing of approximately 20 cm.

To apply the experimental treatments, chicken manure was incorporated into the soil at the specified rates and thoroughly mixed to a depth of 30 cm. Potassium fertilizer was applied as potassium sulfate in bands along the crop rows. The pinto bean cultivar ‘Sadri’, obtained from the Semnan National Agricultural Research Station, was used as the plant material. Seeds were sown at a depth of 5 cm, and to facilitate uniform germination and minimize soil surface compaction, the seeds were covered with a thin layer of fine sand.

The first irrigation was performed immediately after sowing, and subsequent irrigations were applied daily using the flooding method, following the conventional agricultural practices of the region. Harvesting was conducted at full physiological maturity. Yield components, including number of pods per plant, seed yield, harvest index, and seed protein content, were recorded.

Seed nitrogen concentration was determined using the Kjeldahl method (Pansu and Gautheyrou, 2006), and seed protein content was calculated by multiplying

Table 2. Characteristics of the 70% decomposed chicken manure used in the experiment

Category	Parameter	Unit	Value
Physical	Maximum humidity	%	10.00
Physical	Particle size / granule form	—	Not reported
Chemical	Total nitrogen (N)	%	2.00
Chemical	Available phosphorus (P_2O_5)	%	1.00
Chemical	Water-soluble potassium (K_2O)	%	2.00
Chemical	Total sulfur (S)	%	7.00
Chemical	Organic carbon	%	20.00
Chemical	pH	—	8.42
Chemical	EC	dS m^{-1}	4.28
Biological	Microbial content	—	Not reported
Biological	Organic matter activity	—	Not reported

nitrogen concentration by a conversion factor of 6.5. At the end of the growing season, soil samples were collected from the 0–30 cm depth to evaluate post-harvest soil properties.

Soil water infiltration rate was measured using the double-ring infiltrometer method. Water infiltration was recorded at one-minute intervals during the first five minutes, at five-minute intervals until 30 minutes, and subsequently at ten-minute intervals until 90 minutes. The final infiltration rate was determined once a near-constant infiltration rate was reached. All data were subjected to analysis of variance (ANOVA) using the SAS statistical software. Treatment means were compared using Duncan's multiple range test at the 5% probability level.

RESULTS AND DISCUSSION

The studied traits of pinto beans

Analysis of variance revealed that chicken manure and potassium fertilizer significantly influenced pinto bean performance (Table 3). Chicken manure had a highly significant effect ($p \leq 0.01$) on seed yield, number of pods per plant, harvest index, and seed protein content, indicating its strong role in improving both productivity and seed quality. Potassium fertilizer also significantly affected these traits, particularly seed yield and harvest index, highlighting its importance in reproductive development and assimilate partitioning. Moreover, the interaction between chicken manure and potassium fertilizer was significant for seed yield (Table 6), suggesting that the effectiveness of potassium fertilization depend on the level of organic amendment applied. Comparison of the averages of the obtained data showed that chicken manure up to 5 kg ha^{-1} had no significant difference with no fertilization, but the application of 15 t ha^{-1} of chicken manure significantly increased seed yield (Table 4). According to Table 5, the use of potassium fertilizer significantly increased seed yield compared to the control, but there was no significant difference between fertilizer rates (Table 5). These results indicate the important and useful role of both groups of organic and chemical fertilizers in crop production. Tao et al. (2022) reported a 43% increase in fruit yield of cherry tomato due to the use of chicken manure compared to the control. The use of organic matter increases organic carbon and nitrogen, resulting in the availability of soil nutrients and ultimately increasing yield. Potassium is also one of the most consumed plant nutrients; thus, adding it to the soil will increase yield. In the research of Tang et al. (2024), it was reported that tartary buckwheat yield increased due to the use of potassium fertilizer.

Table 3. Characteristics of the 70% decomposed chicken manure used in the experiment

Source of variance (SOV)	df	Number of pods per plant	Seed yield	Harvest index	Protein
Replication	3	0.33	3412.15	4.12	1.84
Potassium fertilizer (A)	2	56.41 **	68421.56 **	29.00 **	5.36 **
Error	6	3.28	3264.76	3.21	2.64
Chicken manure (B)	2	28.69 **	468120.39 **	38.00 **	14.24 **
A × B	6	3.10 ns	1344.95 **	6.18 ns	0.59 ns
Error	18	1.52	3341.60	2.20	2.38

Remarks: *, ** and ns are significant at 5% and 1% of significance levels, and non- significant, respectively.

Table 4. Effects of chicken manure on the studied traits of pinto bean

Levels of chicken manure (t.ha^{-1})	Number of pods per plant	Seed yield (Kg.ha^{-1})	Harvest index (%)	Protein (%)
0	19.30 b	1223.12 c	27.50 c	22.40 b
5	21.40 b	1245.50 bc	28.60 bc	23.30 a
10	23.20 a	1343.70 bc	30.20 ab	23.60 a
15	23.60 a	1469.20 a	32.10 a	24.50 a

Remarks: Means followed by the same letters in the same column are not significantly different based on the DMRT at α 5%.

Table 5. Effects of potassium fertilizer on the studied traits in Pinto bean

Levels of potassium fertilizer ($kg.ha^{-1}$)	Number of pods per plant	Seed yield ($kg.ha^{-1}$)	Harvest index (%)	Protein (%)
0	18.40 d	1228.11 a	28.30 a	21.20 b
100	22.20 a	1394.40 b	28.30 b	23.20 a
175	23.60 b	1445.50 b	30.40 b	25.30 a
250	25.50 c	1643.70 b	32.80 c	27.60 a

Remarks: Means followed by the same letters in the same column are not significantly different based on the DMRT at α 5%.

Table 6. Seed yield under combined chicken manure × potassium fertilizer treatments

Chicken manure ($t\ ha^{-1}$) K ($kg\ ha^{-1}$)	0	100	175	250
0	1102.64 a	1152.20 ab	1212.50 bc	1311.20 c
5	1106.20 a	1154.40 ab	1214.20 bc	1316.40 c
10	1110.40 a	1160.70 ab	1220.30 bc	1328.60 c
15	1123.20 a	1165.60 ab	1228.10 bc	1332.50 c

Remarks: Means followed by the same letters in the same column are not significantly different based on the DMRT at α 5%.

In the study conducted by Ahmadi and Arian (2022) on the effect of poultry manure on Soybean, the results showed that chicken manure had positive effects on yield and yield components.

The results of this study showed that the highest number of pods per plant was obtained with the use of 15 tons per hectare of chicken manure. Although this treatment was in the same statistical group as the use of 10 tons per hectare of chicken manure, the use of chicken manure at a rate of 15 tons per hectare increased the number of pods per plant by 22.2% compared to the control (Table 4). With increasing potassium fertilizer rate, the number of pods per plant increased from 22.2 in the 100 kg ha^{-1} potassium fertilizer treatment to 25.5 in the 250 kg ha^{-1} treatment (Table 5).

Potassium fertilization significantly increased seed yield relative to the control (Table 5), although yield differences among potassium rates were not always statistically different. The highest potassium rate (250 kg ha^{-1}) resulted in the greatest seed yield and harvest index, indicating improved reproductive efficiency. Potassium plays an important role in enzyme activation, osmotic regulation, and carbohydrate translocation from source leaves to developing seeds. The observed increase in seed protein content under potassium fertilization further suggests enhanced nitrogen assimilation and improved metabolic activity during seed development.

Seed protein content also increased significantly with chicken manure application, reflecting enhanced nitrogen availability and uptake. Chicken manure contains readily mineralizable nitrogen forms, which can be gradually released during the growing season, thereby supporting protein synthesis during seed filling. The absence of a strong response at lower manure rates suggests that a threshold level of organic input is required to substantially improve nitrogen nutrition and seed quality. Such a situation was also observed between the first rate of potassium fertilizer and its other rates (Tables 4 and 5). The study of Rasool et al. (2023) reported that the application of poultry manure increased grain yield and harvest index of maize varieties, which is consistent with our results.

Soil Properties

Soil physical properties responded strongly to chicken manure application (Tables 7). Saturated moisture content, total porosity, bulk density, and final infiltration rate were all significantly affected by organic fertilizer. Increasing chicken manure rates led to a progressive improvement in soil water infiltration, with the highest final infiltration rate observed at 15 t ha^{-1}. This progress can be attributed to enhanced soil aggregation and increased continuity of macro- and mesopores resulting from higher organic matter inputs. The use of organic

Table 7. ANOVA for the effects of chicken manure and potassium fertilizer application on soil physical properties

Source of variance	df	Saturated moisture	Porosity	Bulk density	Final infiltration rate
Replication	2	0.034	3.15	2.12	16.84
Potassium fertilizer(A)	4	0.010 ns	0.32 ns	0.00 ns	411.30 *
Error	1	0.002	0.08	5.21	12.64
chicken manure(B)	2	8.690 **	5.39 *	0.01 *	1582.20 **
A × B	12	0.063 **	0.31 ns	0.00 ns	63.50 *
Error	8	0.502	1.60	13.20	0.20

Remarks: *, **: significant at 5% and 1% significance levels; ns : non- significant

and chemical fertilizers has undeniable effects on the physical behavior of the soil. The results of the analysis of variance indicate that both organic and chemical fertilizers had a significant effect on the intensity of water penetration in the soil (Table 7). According to Table 7, the application of chicken manure caused a significant increase in final infiltration rate compared to the control treatment at the level of five percent. Conversely, the use of potassium fertilizer significantly reduced final infiltration rate average from 48 mm h^{-1} (without potassium) to 33 mm h^{-1} after treated with potassium fertilizer (Table 7). Mahmoud et al. (2024) also reported an increase in available water with the use of chicken manure.

According to Table 7, chicken manure treatment had a significant effect on the saturated moisture content at 1% significance level, while the application of potassium fertilizers did not show any significant effect. The average saturated moisture content significantly increased by 13.5% in the 15 t ha^{-1} chicken manure treatment compared to the control (Figure 1). This increase in saturated moisture content can be due to the increase in final infiltration rate as affected by organic matter. Organic matter affects the formation and stability of soil aggregates by binding soil particles, increasing the hydrophobicity of soil aggregates, enhancing microbial activity and root growth (Sonsri and Watanabe, 2023).

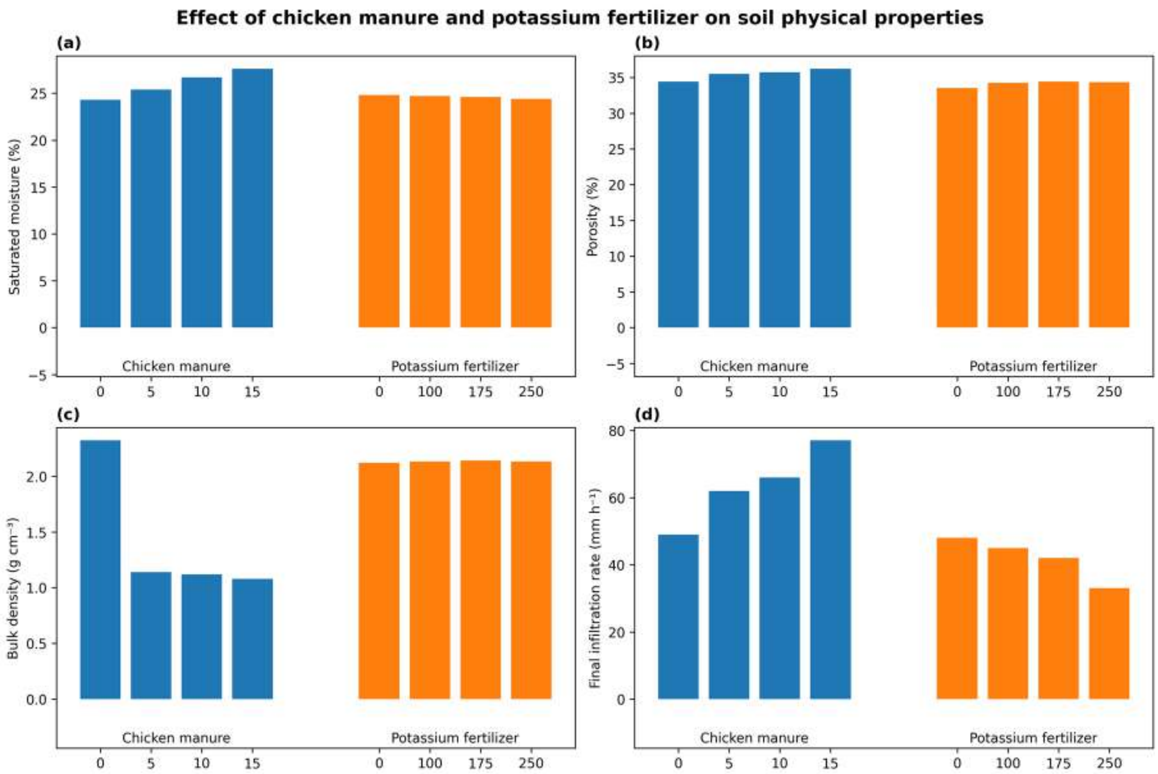

Figure 1. Effects of chicken manure and potassium fertilizer rates on soil physical properties, including saturate moisture, porosity, bulk density, and infiltration rate

The significant reduction in bulk density with increasing manure application further confirms the positive role of organic matter in loosening soil structure and reducing compaction. Lower bulk density facilitates root penetration, enhances gas exchange, and improves water movement within the soil profile. Concurrently, increased total porosity and saturated moisture content indicate improved soil water-holding capacity, which is particularly beneficial in semi-arid environments where water availability is a major limiting factor for crop growth. According to the results obtained, the use of 15 tons per hectare of chicken manure caused an increase of 6.3% in total porosity and a significant decrease of 53.4% in bulk density compared to the control (Figure 1). It can be said that the application of organic matter through soil agglomeration and improvement of soil structure increase soil permeability and water retention capacity in the soil, thereby leading to a decrease in the bulk density of the soil. Agbede (2025) investigated the effect of poultry manure on soil properties and reported an increase in soil porosity and moisture content, as well as a decrease in bulk density. These findings indicated that organic matter, as a structural reinforcer, causes particle homogeneity, and it can be said that organic fertilizers have played a much more important role in improving the physical properties of the soil than chemical fertilizers. In contrast, potassium fertilizer application had a negative effect on soil water infiltration rate, reducing it from 48 mm h^{-1} in the control to 33 mm h^{-1} at the highest potassium level. This reduction may be associated with increased salt concentration in the soil solution, which can promote clay dispersion, reduce aggregate stability, and restrict water movement. Potassium fertilizer did not significantly affect saturated moisture, porosity, or bulk density, indicating that chemical fertilization alone has limited capacity to improve soil physical structure and may even exert adverse effects under certain conditions. Chicken manure application significantly altered soil chemical characteristics, including electrical conductivity (EC), pH, soil organic carbon, and available phosphorus (Figures 2 and 3). The increase in EC with manure application reflects the release of soluble ions during organic matter decomposition. Although EC values increased, they remained within a range that did not negatively affect pinto bean growth, as evidenced by the simultaneous increase in yield and yield components.

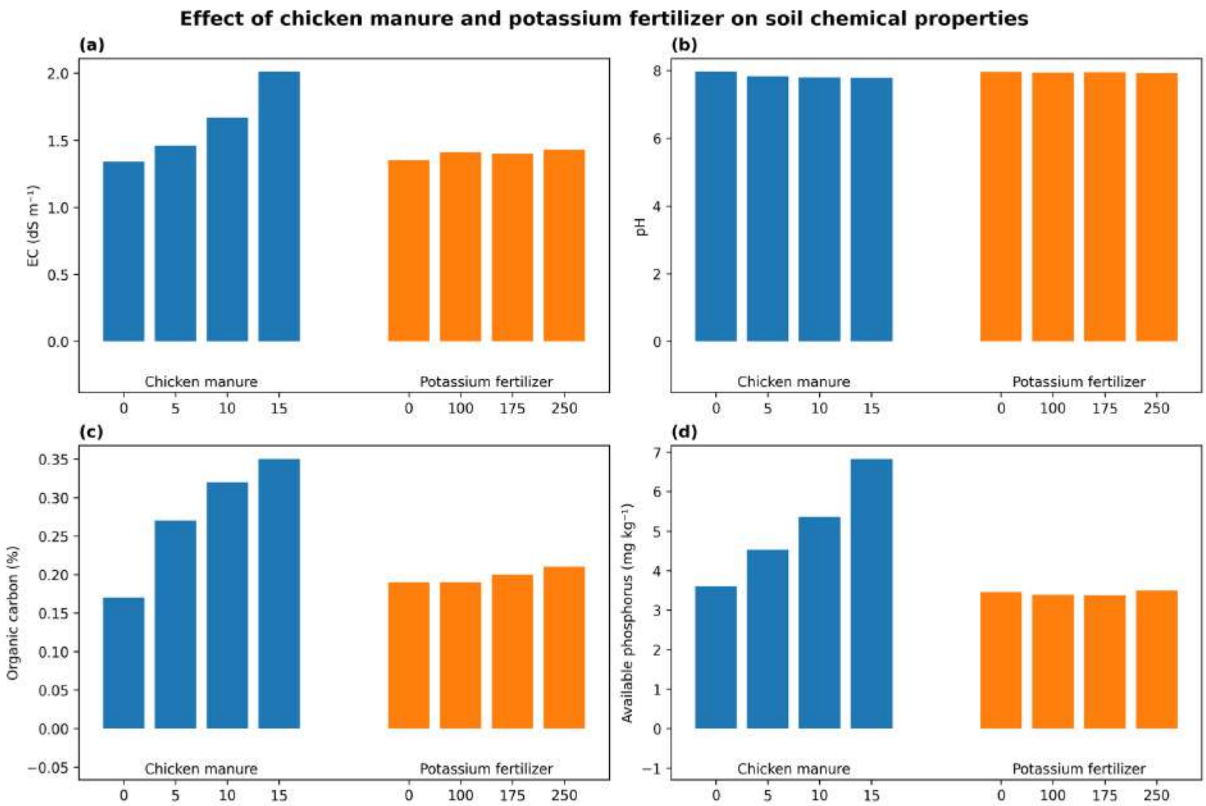

Figure 2. Effects of chicken manure and potassium fertilizer rates on soil chemical properties, including EC, pH, organic carbon, and available phosphorus

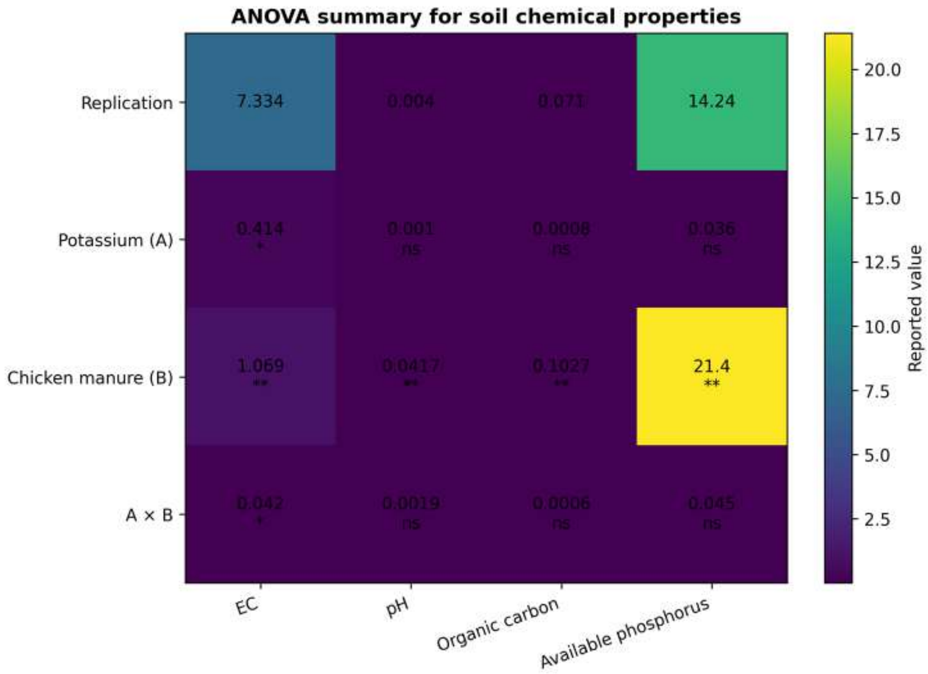

Figure 3. ANOVA results showing the significance of potassium fertilizer, chicken manure, and their interaction on soil chemical properties

Soil pH decreased significantly with increasing manure rates, which may be attributed to the production of organic acids and increased carbon dioxide partial pressure during organic matter mineralization. A moderate reduction in soil pH can enhance nutrient availability, particularly phosphorus, in calcareous or alkaline soils. The results showed that chicken manure had a significant effect at 1% significance level on all selected chemical properties (Figure 2). By adding chicken manure to the soil, the EC value significantly increased compared to the control (Figure 3). This increase in EC could be due to the gradual increase in salt in the soil solution as a result of the decomposition and dissolution of organic matter. These results are consistent with the findings of Abd Alshammari and Al-Wotaify (2024) regarding the increase in soil salinity due to the use of animal manure and compost. Furthermore, the application of 15 tons per hectare of chicken manure resulted in an average decrease in pH by 13.2% when compared to the control treatment (Figure 3), indicating that the use of chicken manure significantly reduced the pH of the soil. The reason for this decrease in pH could be an increase in carbon dioxide gas pressure or the creation of organic acids as a result of the use of organic matter (William and Horton, 2004). This is despite the fact that, according to Figure 3, potassium application had no significant effect on pH change.

The most significant effect of chicken manure was observed on soil organic carbon, which increased by 105.8% at 15 t ha^{-1} compared to the control. This substantial increase reflects both the direct input of organic carbon from manure and the accumulation of relatively stable organic compounds. Enhanced soil organic carbon improves nutrient retention, cation exchange capacity, and microbial activity, thereby strengthening overall soil fertility. One of the important effects of organic matter application is the increase in soil organic carbon. The application of chicken manure had a significant effect on the amount of soil organic carbon, while the use of potassium fertilizer did not show a significant effect in this regard (Figure 3). With the use of 15 tons per hectare of chicken manure, the average soil organic carbon increased by 105.8% compared to the control treatment (Figure 3). It can be said that chicken manure increases the amount of soil organic carbon by containing compounds such as lignin and polyphenols that are resistant to decomposition, which in the presence of favorable conditions for microorganisms, enzyme activities also increase. Osakwe et al. (2025) reported an increase in soil organic carbon due to the use of poultry manure. In fact, chicken manure, as an organic matter, affected bean growth by improving soil characteristics, so that a direct relationship was observed between the improvement of these indicators and an increase in seed yield, harvest index, and seed protein content. The use of organic matter can provide different amounts of nutrients to the soil, depending on the type of chemical constituents and the rate of their decomposition. Available phosphorus also significantly increased (89.4%) with manure application (Figure 3), likely due to reduced phosphorus fixation and increased mineralization of organic phosphorus compounds. Organic matter can complex calcium and other cations responsible for phosphorus immobilization, thereby enhancing phosphorus availability to plants. It can be said that chicken manure, by increasing the amount of soil organic matter, increases the availability and, as a result, greater absorption of phosphorus by the plant. Ferreira et al. (2024) reported a significant increase in available phosphorus with the application of biochar and chicken manure. Potassium fertilizer primarily affected soil EC and had no significant effect on soil pH, organic carbon, or available phosphorus. This finding emphasizes that potassium fertilizer contributes mainly to short-term nutrient supply and does not improve the inherent fertility or buffering capacity of the soil. The strong improvement in pinto bean yield and seed quality observed in this study can be directly linked to the positive changes in soil physical and chemical properties induced by chicken manure application. Improved soil structure, enhanced water infiltration and retention, increased organic carbon, and greater nutrient availability collectively created a more favorable root-zone environment. These conditions enhanced nutrient uptake efficiency, photosynthetic activity, and assimilate partitioning toward reproductive organs. The significant interaction between chicken manure and potassium fertilizer for seed yield indicates that organic amendment improved the efficiency of potassium utilization by plants. By improving soil structure and nutrient dynamics, chicken manure likely enhanced potassium availability and uptake, thereby amplifying its positive effects on crop performance. Overall, these results underscore the importance of integrated organic–chemical fertilization strategies for improving soil quality and sustaining crop productivity, particularly in semi-arid soils with low organic matter content.

CONCLUSIONS

The application of chicken manure and potassium fertilizer significantly improved pinto bean yield and yield components under field conditions. Chicken manure, particularly at higher application rates, enhanced seed yield, harvest index, and seed protein content, while potassium fertilization further supported yield improvement. Chicken manure significantly improved soil physical properties by increasing water infiltration, saturated moisture, and porosity while reducing bulk density. It also enhanced soil chemical properties by increasing soil organic carbon and available phosphorus while lowering soil pH. In contrast, potassium fertilizer had limited effects on soil properties and primarily increased soil electrical conductivity. Overall, this study highlights the important role of chicken manure in improving soil quality and creating favorable conditions for pinto bean production. The integration of organic and chemical fertilizers can be considered an effective and sustainable nutrient management strategy for semi-arid agroecosystems.

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