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Research Article

Effects of Inorganic and Organic Fertilizers on the Growth of Chickpea Plant and Soil Organic Carbon and Nitrogen Contents

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ABSTRACT

Rapid economic and population growth has led to rising atmospheric greenhouse gas emissions, necessitating adequate soil and crop management for enhanced CO_2 absorption. Plant and soil microorganisms have various effects on atmospheric CO_2 capturing. Chickpea (*Cicer arietinum* L.), a leguminous plant, establishes a symbiotic association with rhizobium bacteria and mycorrhizal fungi, enabling it to fix atmospheric nitrogen (N_2) and sequester more CO_2 into the biomass and then to the soil. However, the application type of fertilizers influences this plant's growth and soil's capacity to retain carbon (C). In this background, the current research aimed to explore the impact of various organic and inorganic fertilization methods on the growth and nutrient content of chickpea plants and nitrogen content and soil organic carbon. A long-term field trial was started in 1996 at Çukurova University Research Center, with the five treatments such as Control (without fertilizer), Animal manure (25 t ha^{-1}), Mineral fertilizer (NPK), Compost (25 t ha^{-1}), and Mycorrhiza + Compost (10 t ha^{-1}). Chickpeas were planted and harvested in 2020. During harvesting, plant samples at 1 m^2 area, and soil samples at 0 to 15 cm and 15 to 30 cm depths were taken. The shoot, root and pod fresh biomass and tissue C, P, K, N, and Zn concentrations were determined. Similarly, the soil P, organic C and total N concentrations were determined. The results of the study indicate that mineral fertilizer resulted in a notable enhancement in the shoot, root and seed biomass of chickpea plants. Furthermore, mineral fertilizer resulted in a higher concentration of carbon in the roots, while the treatments involving animal manure, compost +AMF, and compost showed higher concentrations of K in both shoots and seeds. Seed P concentration was higher when animal manure was applied and exhibited similarity to the compost treatment. In terms of soil properties, the application of animal manure led to increased levels of soil organic carbon and P. Moreover, the compost treatment showed an increase in organic carbon in deeper soil depth. At 15-30 cm soil depth, both animal manure and compost treatments contributed to improved levels of total nitrogen. The good effects of organic fertilizers on soil fertility and nutrient levels in sustainable farming practices are highlighted by these findings. When compared to mineral fertilizer, animal dung specifically showed considerable improvements in soil organic carbon, nitrogen, and phosphorus.
Keywords: Chickpea, long-term field trial, soil organic carbon, organic fertilizer, and mycorrhizae

INTRODUCTION

In semi-arid climatic regions, such as the Mediterranean part of Turkey, soil degradation issues have resulted in low levels of soil organic carbon (SOC). These regions are characterized by specific challenges, including high temperatures, elevated levels of calcium carbonate ($CaCO_3$) and clay, and intensive tillage practices. Consequently, the decline in SOC has had a detrimental impact on agricultural production. Other contributing factors to the reduction in SOC levels include the burning of crop residues (Ortas, 2029) and accelerated erosion. It is crucial to highlight that effective soil and crop management practices have a substantial influence on various soil properties, including the SOC pool. Specifically, the use of inorganic and organic fertilizers may have a considerable impact on SOC levels. Implementing appropriate soil and crop management strategies, along with judicious utilization of fertilizers, becomes crucial in replenishing and improving the SOC pool in semi-arid regions (Ortas and Lal, 2014).

The application of organic fertilizers is a highly effective strategy for augmenting SOC levels and enhancing crop micronutrient content, surpassing the benefits of using mineral fertilizers alone (Lal, 2009). Increasing the use of organic amendments is regarded as a soil carbon-saving practice, as it helps preserve and build up soil carbon stocks. The addition of favorable impact on soil quality by improving the availability of nutrients, enhancing soil structure, and encouraging a greater abundance and diversity of soil organisms (Ortas, Akpinar and Lal, 2013; Willekens, Vandecasteele and De Neve, 2014). Furthermore, integrating organic amendments serves a crucial function in augmenting the stability of SOM, thereby ensuring its long-term presence and the associated benefits in the soil. Efficiently sequestering SOC is of utmost importance in mitigating greenhouse gas emissions and reducing the carbon footprint associated with agricultural practices (Jarecki and Lal, 2003).

Crop species have a significant impact on improving soil properties by engaging in rhizospheric processes (Ortas and Lal, 2014). These processes involve the interactions between plant roots and the adjacent soil, leading to physical, chemical, and biological enhancements. Legume crops serve a dual purpose in agricultural practices, playing a vital role in human nutrition as well as in enhancing soil fertility/quality through biological N fixation. Amongst the legumes, the chickpea (*Cicer arietinum L.*), is a globally cultivated grain legume crop of significant importance. It holds a prominent position as the third most crucial food legume worldwide. Renowned for its high nutritional value, chickpea serves as a highly nutritious pulse. With a remarkable protein content of 25%, it surpasses all other pulses in this aspect. Additionally, it contains 60% carbohydrates, making it an ideal addition to enhance the nutritional composition of one's diet (Kumar, Berggren and Mårtensson, 2001). Consequently, there exists an opportunity to enhance pulse productivity by improving soil fertility and productivity through various means. This includes increasing SOC, improving the capacity of soil to store moisture, and implementing incorporated practices for nutrient and pest management. By optimizing the nutrient requirements of crops at different stages, the productivity of pulses can be significantly improved within organic production systems. In such systems, the management of organic matter plays a vital role in improving soil fertility and overall productivity (Naik, Patel and Patel, 2014). Many leguminous plants establish tripartite symbiotic relationships involving both arbuscular mycorrhizal fungi (AMF) and rhizobia. The partnership with rhizobia primarily facilitates the conversion of nitrogen in the atmosphere into a usable form, whereas the collaboration with AMF influences the plant's capacity to absorb phosphorus (Champawat, 1990; Lodwig et al., 2003) and micronutrients (Ortaş, 2008). Fertilization also has an impact on the effectiveness of this association, soil C sequestration, and crop productivity.

Despite the extensive use of organic and inorganic fertilizers, limited research has focused on evaluating their long-term effects on SOC levels and crop production. Therefore, the current study aims to close this research gap and provide useful information by conducting a comprehensive evaluation of the long-term impacts of fertilization on plant production and soil quality. The aim of this study is to find out the effect of prolonged (26-years) application of different organic and inorganic fertilizers on SOC and N levels as well as on the growth, and mineral nutrition of chickpea plants. Through this research, we intend to identify the most effective fertilization strategies that promote soil carbon storage, maximize crop productivity, and support long-term sustainability in agricultural systems.

MATERIALS AND METHODS

Site Descriptions and Experimental Setups

A long-term field study was initially established in 1996 within the Menzilat soil series (Typic Xerofluvents), and the soil properties are provided in Table 1. The study site is situated at the Research Farm of Cukurova University (37°-00'54.31''N longitude and 35°-21'21.56''E latitude and 34 m above mean sea level) in Adana-Turkey, which is located in the eastern part of the Mediterranean region. Since 1996, five treatments such as: (i) a control group (no fertilization), (ii) conventional mineral fertilizer (N-P-K ,consisting of 160 kg N ha^{-1}, 83 kg K ha^{-1}, and 26 kg P ha^{-1}, (iii) compost application at a dose of 25 t ha^{-1}, (iv) animal manure application at 25 t ha^{-1} rate, and (v) mycorrhiza inoculation combined with 10 t ha^{-1} of compost addition, have been applied. The study had a completely randomized block design with three replicates. Prior to compost application, the mycorrhizal inoculum cocktail was carefully blended with the compost material. After each harvest, all plots underwent moldboard plowing to a depth of 20 cm. For each cropping season, the organic fertilizers were evenly applied across the soil surface, considering the soil moisture levels immediately prior to sowing. Subsequently, they were incorporated into the uppermost part of the soil, approximately 10-15 cm deep, using a disc harrow. The control and fertilizer-amended plots followed similar tillage practices throughout the experiment.

Table 1. The soil characteristics of Menzilat soil in 1996 were documented by (Ortas and Lal, 2014).

Parameters	Unit	0-15cm Depth		15-30cm Depth	
Clay		318.8	±30.6	333.4	±21.8
Sılt		360.9	±87	379.5	±13.4
Sand		320.3	±23.0	287.2	±16.4
Organic C Soil		0.96	±0.08	0.78	±0.08
İnorganic Carbon	g kg^{-1} soil	3.77	±0.35	3.97	±0.42
Total N		0.08	±0.01	0.07	±0.01
CEC	Cmol^{+} kg^{-1}	20.50	±2.00	17.90	±1.64
pH	H_2O	7.58	±0.66	7.60	±0.71
Salt	%	0.05	±0.00	0.04	±0.00
P		22.60	±2.16	20.20	±2.00
Fe		5.43	±0.82	5.66	±0.58
Mn	mg kg^{-1}	5.74	±0.32	5.31	±0.59
Zn		0.52	±0.05	0.23	±0.02
Cu		1.86	±0.19	1.56	±0.16
AMF spore counts	10 g^{-1} soil	64.00	±11.70	44.00	±2.62

Mean of three replicates ±SD.

Soil and Plant Sampling, Preparation, and Analyses

Soil samples were taken from depths of 0-15 and 15-30 cm, and subjected to a series of preparation and analysis procedures. Initially, the soil samples were air- dried and subsequently ground to attain a fine consistency. Subsequently, the ground samples were passed through a 2 mm sieve for further soil analysis. To accurately determine the total carbon (TC) and nitrogen (N) concentrations in the soil, an additional grinding step was implemented. The soil samples were further ground to a finer consistency and sieved through a 0.25 mm sieve. To determine the inorganic carbon (IC) content, the total calcium carbonate ($CaCO_3$) content of the soil was measured using a calcimeter device of the Schibler type. The concentration of Soil Organic Carbon (SOC) was determined by subtracting the content of soil inorganic carbon from the total carbon content, following the methodology outlined in previous studies conducted by (Ortas, Akpinar and Lal, 2013; Ortas and Bykova, 2020). Finally, the total nitrogen concentration in the soil samples was measured using a carbon nitrogen analyzer device. These analytical techniques and procedures were employed to assess the SOC and total nitrogen concentrations in the soil samples as part of the study.

Chickpea plant samples were collected from an area of 1 m^2 from the center of each plot, and this was done at the same time for samples of pods, seeds, shoots, and roots. The fresh weight of the samples was measured immediately after harvesting. For determining their nutrient level, the samples were washed with distilled water and oven-dried for 72 hours at 60 °C. Then the dried samples were analyzed for total C and N concentrations using a CN elemental analyzer (Fisher-2000) by the dry combustion method. The nutrient concentrations of the plant samples were determined using ICP.

Statistical Analysis and Data Evaluation

The statistical analysis was completed using R version 4.2.2. An analysis of variance (ANOVA) was conducted to evaluate the overall effects of different fertilizers on soil properties and plant development. The least significant difference test (P 0.05) was then applied to see whether there were any significant differences between the treatment means.

RESULTS AND DISCUSSION

Effect of Organic and Inorganic Fertilizers on Chickpea Plant growth and Nutrition

Plant Biomass Production

The influence of long-term inorganic and organic fertilizers on the fresh weights of shoots, roots seeds of the chickpea plant were examined, and the findings are illustrated in **Error! Reference source not found.**. The mineral fertilizer treatment exhibited significantly higher fresh weights of shoots (17.83 t ha^{-1}), pods (8.8 t ha^{-1}), and roots (0.58 t ha^{-1}) compared to all other treatments (Figure 1).

Shoot and pod fresh weights were not significantly different between mineral and compost + AMF treatments as well. This could be the contribution of AMF to enhancing nutrient access to host plants. The substantial growth observed in plants treated with mineral fertilizers can be attributed to the high concentration of nutrients added in soluble and readily available forms (Sarret et al., 2002). The accessibility of nutrients likely facilitated the continued growth and development of chickpea plants. Nevertheless, the nutrients incorporated in manure and compost are typically present in less readily available forms for plants compared to their mineral counterparts. While manure and compost contribute to the total nutrient content, the availability of these essential nutrients for plant growth depends upon their breakdown and release from the organic constituents (Rosen and Bierman, 2005). This process of nutrient release from organic sources may take longer and is influenced by factors such as microbial activity and environmental conditions.

Nutrient Concentrations in Plant Tissues

Carbon and Nitrogen Concentration in Seed, Shoot and Root Tissue

Following harvest, the levels of carbon (C) and nitrogen (N) in various plant tissues, such as seeds, shoots, and roots, were measured. With the exception of root C concentration, none of the factors shown in Figure 2 shows any discernible changes. Between 35.41% (in the control) and 40.17% (in the compost + AMF treatment), the values for shoot C varied. Root C content varied significantly between treatments, with the mineral treatment having the highest value (49.24%) and the manure (44.06%) and compost (42.48%) treatments coming in second and third, respectively. The root C concentration was lowest in the control treatment (37.29%). Seed C contents ranged from 39.27% to 46.55% and remained largely constant between treatments.

Regarding N concentrations, the values ranged from 1.85% to 2.27% in shoot tissue, 1.43% to 3.28% in root tissue, and 4.41% to 6.17% in seed tissue. The manure treatment resulted in the highest levels of N in the roots. The compost +AFM treatment also showed the highest seed N concentrations (6.17%). These findings suggest that the addition of organic nutrient sources can enhance N accumulation in plant tissues, particularly in the root and seed tissues. The lack of significant differences in shoot and seed C and N concentrations across treatments implies that the nutrient sources and management strategies may have a limited impact on these parameters. However, the observed differences in C concentrations in the roots suggest that the treatments may have impacted the allocation patterns of C within the plant, specifically in the shoot and root tissues.

The use of organic sources resulted in higher plant N concentrations when compared to both the control and mineral fertilizer treatments. In previous works, it has been reported that organic fertilizer applications exhibited higher concentrations of nutrients in the plant tissue compared to the control and mineral treatments. In line with this finding, Özkan, Asri, Demirtaşi and Arı (2013) also reported that various organic and inorganic fertilizers applied in greenhouse pepper cultivation led to increased N content in pepper plants relative to the control treatment. Furthermore, Chirinda, Olesen and Porter (2012) found that root C content showed higher levels in organic fertilizer-based systems for spring barley in 2008, as well as in wheat (Akşahin, Işik, Öztürk and Ortaş, 2021).

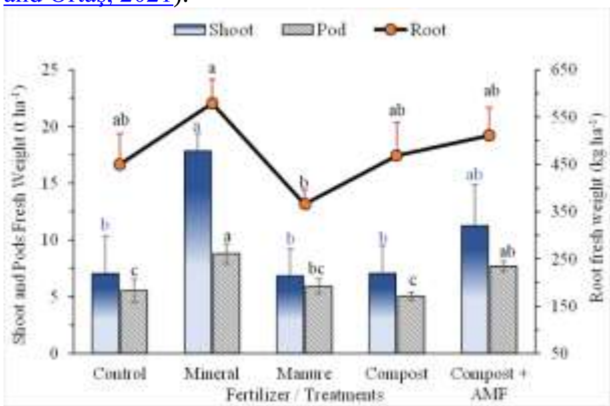

Figure 1. Effect of different fertilizer applications on fresh biomass of chickpea plant.

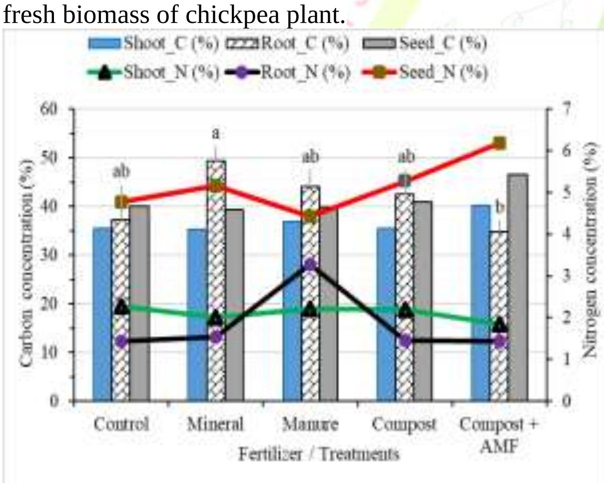

Figure 2. Effect of different fertilizer applications on C and N concentrations of plant tissues

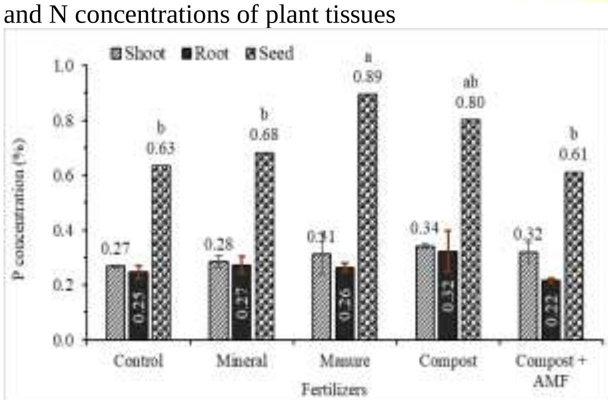

Figure 3. Effect of different fertilizer applications on P concentration in the chickpea plant tissues.

Phosphorus, Potassium and Zinc Concentrations in the Plant Tissues

The uptake of P by seed in treatments that received animal manure (0.89%) was relatively higher, though it was statistically similar to the compost treatment (Figure 3). There were no significant differences observed in the parameters for root and shoot P concentration, as indicated in Figure 3. However, the maximum shoot P concentration (0.34%) was found to be under the compost application. The same result was seen in the root, where the highest value (0.32%) was in the compost treatment.

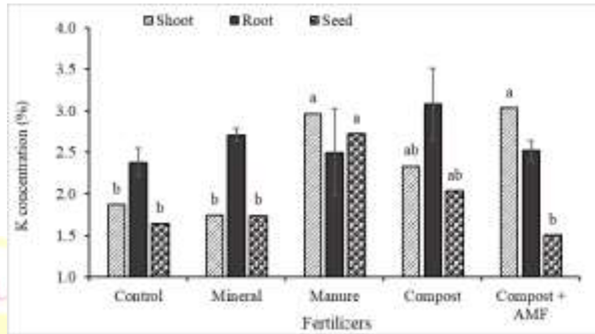

Figure 4. Effect of different fertilizer application on K concentration

Figure 4 shows that, unlike root tissue, the concentration of potassium (K) in the shoot and seed was significantly affected by fertilizer applications. The concentration of K in the seeds (2.72%) was relatively higher in treatments where animal manure was applied, and statistically did not differ from the compost treatment. The simultaneous application of compost and AFM resulted in the highest levels of K in the shoot (3.04%), which was statistically similar to the animal manure treatment (2.96%). There were no noticeable variations in root K concentrations across the different treatments. However, relatively, the maximum concentration of K in the roots (3.08%) was found when compost was applied.

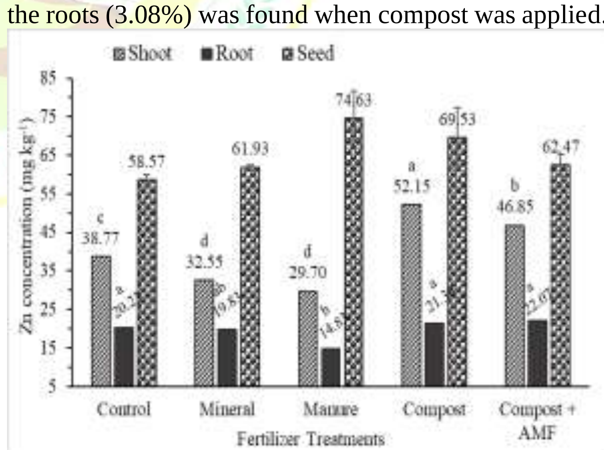

Figure 5. Effect of different fertilizer application on Zn concentration

The results presented in Figure 5 demonstrate significant differences in zinc (Zn) concentration in plant tissues, except in the seeds. Shoot Zn concentration exhibited notable variations, with the compost treatment showing statistically the highest value of 52.15 mg kg^{-1}, followed by compost + AFM (46.85 mg kg^{-1}), minerals (32.55 mg kg^{-1}), and manure (29.70 mg kg^{-1}). In the roots, no significant variations were found between the treatments, except for the manure treatment, which was statistically the lowest (14.83 mg kg^{-1}). The compost + AFM treatment showed the highest Zn level of 22.07 mg kg^{-1} in the root. The seed Zn concentration ranged from 58.57 mg kg^{-1} (in the control) to 74.63 mg kg^{-1} (in the manure treatment), and there was no statistical difference among the treatments.

In general, the animal manure treatment showed the highest concentrations of K and P in both the shoots and seeds, whereas the compost treatment exhibited the highest concentrations of Zn in root and shoot tissue and the highest concentration of P in the root. The Zn concentration in the seed was highest under compost + AMF treatments. Nitrogen-fixing plants contain higher mineral nutrients, especially micronutrients, compared to non-N-fixing plants. Therefore, organic fertilizers resulted in higher concentrations of P, K and Zn in the chickpea plant tissues when compared to control and mineral fertilizers. These might be attributed to the presence of these nutrients in the organic materials, primarily found in their feedstock's (Li et al., 2007; Ortas, 2012a).The phosphorus and potassium content present in the organic fertilizers should be considered when calculating the application of phosphorus and potassium fertilization (Richner, Flisch, Sinaj and Charles, 2010). Many other studies, such as Kumar and Jat (2010) also found that organic fertilizers can boost plant nutrition because of their source of multiple nutrients. As a result, the improved plant growth can be credited to the enhanced availability of nutrients obtained from organic sources. AMF also enhances the absorption of nutrients with limited mobility in the soil, such as P and Zn, and this has been linked to higher nutrient content in plants, leading to increased levels of zinc in seeds (Hayman, 1982; Ortas, 2012a, b).

Effect of organic and Inorganic Fertilizers on Soil Properties

The results for the long-term influences of different fertilizers on SOC, total Nitrogen (TN), available soil P and soil C:N ratio at 0 -15 and 15-30 cm depths are presented in Table 2. The soil OC at 0-15 cm depth, soil TN at 15-30 cm depth, and soil C:N ratio and P concentration at both depths were significantly ($P < 0.05$) changed by fertilizer treatments. At the 0-15 cm soil depth, animal manure treated plots have a significantly higher soil OC of 2.05%, followed by compost treated plots (1.96%). However, at the depth of 15-30 cm, relatively higher soil OC (2.64%) was found under compost treatment, followed by compost +AMF and animal manure. Generally, there was a noticeable trend toward an increment in the soil OC in the plots receiving organic fertilizers over inorganic fertilizers. This could be attributed to the fact that the incorporation of organic materials from organic fertilizers has a greater impact compared to inorganic sources.

Furthermore, there was a slightly higher soil organic carbon (SOC) pool at a surface depth (0 to 15 cm), as compared to 15 to 30 cm depth. This might result in a lower rate of decomposition of soil OC in the sub-soil. Ortas and Lal (2014) and (Ortas and Lal, 2012) supports this explanation, suggesting that the inclusion or integration of organic materials and the presence of intact soil aggregates contribute to the preservation of SOC in deeper soil layers.

Table 2. Effect of different fertilizer application on selected soil properties

Fertilizers	Soil depth	Soil OC (%)	Soil TN (%)	C:N ratio	Available P (mg kg^{-1})
Control	0-15 cm	1.69 bc	0.133	13.05 a	2.36 d
Mineral		1.37 d	0.142	9.63 b	9.01 c
Animal Manure		2.05 a	0.192	10.66 ab	47.62 a
Compost		1.93 ab	0.180	10.74 ab	21.65 b
Compost + AMF		1.56 cd	0.133	11.71 ab	7.78 c
LSD (P<0.05)		0.30	0.025	3.10	2.36
Control	15-30 cm	1.69	0.131 b	13.00	4.17 c
Mineral		1.32	0.124 b	10.53	5.25 c
Animal Manure		1.88	0.182 a	10.04	45.28 a
Compost		2.64	0.189 a	14.13	19.00 b
Compost + AMF		1.88	0.134 b	13.81	5.81 c
LSD (P<0.05)		1.35	0.070	5.87	5.59

Means followed by the same letter are not statistically different for each depth.

Significantly, the highest soil P concentration (47.62 mg kg^{-1} at 0 to 15 cm, and 45.28 mg kg^{-1} at 15 to 30 cm depths) was found in the animal manure treatment compared to both the control and other treatments. At a depth of 0 to 15 cm, there was no significant difference between the treatments in terms of TN, whereas a notable variation was found at a depth of 15-30 cm. It has been found that animal manure (0.182 %) and compost (0.189 %) resulted in significantly higher soil TN compared to the rest of the treatments. The increased soil organic matter (SOM) in these treatments may have contributed to higher soil TN levels. Moreover, it was noted that the soil carbon-to-nitrogen (C:N) ratio was lowest (≤10) in the mineral fertilizer treatment, while it exceeded 10 in the other treatments.

Correlation Analysis

A Pearson correlation analysis was employed to evaluate the relationship between the variables, and the correlation result is indicated in Figure 6. A positive and highly significant correlation ($P<0.001$) was observed, indicating a strong association between seed K and seed P, seed Zn and Seed P, seed K and soil P at both depth, soil OC and soil TN at both depths, and soil P and soil TN (Figure 6). On the other hand, soil P at both depths had a strong negative relationship ($P<0.05$) with shoot and root Zn concentrations. The soil P level has a negative impact on Zn uptake by plants. Additionally, the SOC level significantly influences the accessibility of plant nutrients such as N and P, highlighting the importance of SOC management to enhance nutrient content in the soil.

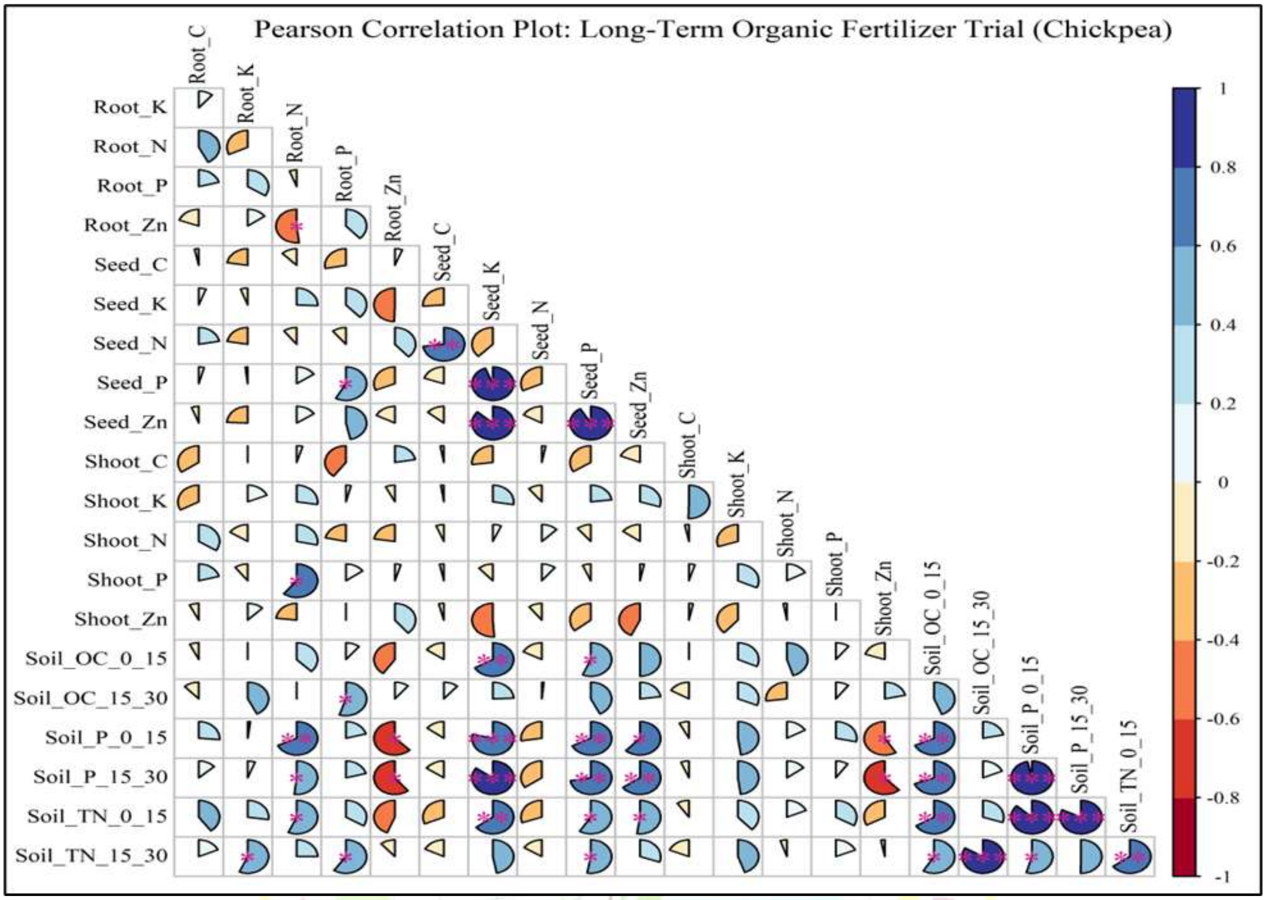

Figure 6. Correlation plot for dependent variables. The larger the circle, the stronger the associations among the variables. Deep blue colors (to top) show a strong positive correlation while deep red colors show a strong negative correlation. 0 -15 and 15 -30 are the soil sampling depths in cm.

CONCLUSION

In effect of various organic and inorganic fertilizers on the growth of chickpea plants, nutrient absorption, and the concentrations of organic carbon (OC) and nitrogen (N) in the soil were investigated. The results revealed that mineral fertilizer was the most effective in enhancing plant biomass (shoot, root, and pod) compared to other treatments. Even though maximal root N was demonstrated following manure application, the N concentrations in various plant tissues were not considerably altered. With the exception of compost + AMF, the C concentration in the roots was statistically similar across all treatments but was substantially greater in the mineral treatment. Phosphorus (P) concentrations in the roots and shoots did not differ noticeably. However, the P concentration in the seed was higher under animal manure, and statistically similar to compost. The plant tissues exhibited higher K and P concentrations, but a lower Zn concentration when treated with animal manure.

The fertilizer treatments also affect the soil's properties. Animal manure treatment resulted in significantly higher SOC and total nitrogen (TN) concentrations compared to other treatments. Organic fertilizers contributed to increased soil OC and TN, while mineral fertilizers had a lower carbon-to-nitrogen (C:N) ratio. These findings point out the potential of organic fertilizers to improve soil quality and its nutrient levels, contributing to sustainable agriculture. In conclusion, the use of mineral fertilizers has led to a significant and visible increase in plant biomass, while the use of animal manure has led to higher concentrations of OC, N, and P in the soil. These results advance knowledge of how soil nutrients and chickpea growth are affected by organic and inorganic fertilizers. To maximize their potential, more research is required on the carbon footprint, economics, and environmental sustainability of these fertilizer treatments.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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