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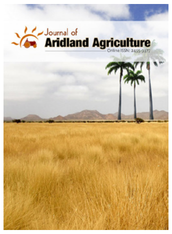
Research Article



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Effect of potassium foliar spraying and sheep manure application on soil nutrient availability and growth of pomegranate seedlings (*Punica granatum* L. var. Selimi)

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ABSTRACT

Proper management of soil nutrients is crucial for optimizing plant growth and fruit production. This study investigates the impact of potassium foliar spraying and sheep manure application on available nitrogen (N), phosphorus (P), and potassium (K) levels in soil, as well as the growth performance of pomegranate (*Punica granatum* L. var. Selimi) seedlings. Treatments included four potassium spray levels (0, 10, 20, and 30 g/L) and four sheep manure application rates (0, 6, 12, and 18 t/ha). Results showed that foliar spraying with 20 g/L potassium significantly enhanced soil nutrient availability (N: 68.40 mg/kg, P: 13.35 mg/kg, K: 22.35 mg/kg). This treatment also improved seedling growth, yielding the tallest main stem (106.60 cm), the highest number of leaves (321.73), the largest leaf area (1540.23 cm^2), and the greatest chlorophyll content (43.30 SPAD). Additionally, the combination of 20 g/L potassium with 18 t/ha sheep manure resulted in the highest overall plant growth metrics. These findings suggest that integrating potassium foliar sprays with organic fertilization enhances soil nutrient availability and promotes vigorous growth in pomegranate seedlings.

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INTRODUCTION

Fruits are a vital source of nutrition for human life, and the maintenance of their quality is critical as the global population is increasing and climate change accelerates. Among these fruits, the pomegranate (*Punica granatum* L.), a member of the Punicaceae family, holds significant importance due to its nutritional and economic value. Widely cultivated in Mediterranean regions for commercial purposes, pomegranates are valued for their rich content of vitamins, minerals, antioxidants, and unique plant compounds that are rarely found in other fruits (Sabale *et al.*, 2020). In Iraq, the Salimi cultivar, predominantly grown in the central region, is particularly notable for its large, red-skinned fruit with minimal yellowing, juicy red arils, and a flavorfull profile ranging from sour to sweet. Enhancing the production and accessibility of pomegranate is essential not only for meeting nutritional needs but also for supporting economic growth and food security (Valero-Mendoza *et al.*, 2023).

The growth and development of pomegranate plants, like all crops, are heavily influenced by the availability of essential nutrients in the soil. Among these, potassium plays a pivotal role in various physiological processes, despite not contributing directly to the formation of organic compounds within the plant. Potassium is involved in activating over 60 enzymes, regulating stomatal function, and promoting cell division, particularly in meristematic tissues, which are crucial for plant growth (Torabian *et al.*, 2021). Additionally, potassium enhances a plant's resilience to adverse environmental conditions, such as extreme temperatures and water stress, while also reducing susceptibility to pest and disease attacks (Johnson *et al.*, 2022).

Organic fertilizers, derived from decomposed plant and animal matter, have long been used to improve soil fertility and enhance nutrient availability for plants. Recent studies have demonstrated that organic fertilization significantly benefits plant growth, leading to increased plant height, leaf number, shoot biomass, and chlorophyll content (Abdel-Sattar *et al.*, 2021; Choudhary *et al.*, 2022). Specifically, the application of sheep manure has been shown to improve leaf area, chlorophyll levels, and potassium content in pomegranate seedlings, highlighting its effectiveness as an organic amendment (Hamad & Abd, 2013).

This study aims to investigate the response of pomegranate seedlings to the combined application of organic fertilizers and potassium sprays, focusing on nutrient availability and its impact on vegetative growth indicators. By exploring these interactions, the research seeks to provide insights into optimizing pomegranate cultivation practices for improved yield and quality.

MATERIALS AND METHODS

This study was conducted at the Al-Hindiya Horticultural Station in Karbala Governorate, under the General Company for Horticulture and Forestry, Ministry of Agriculture, from March 15 to November 15, 2023. One-year-old pomegranate seedlings of the Salimi cultivar, averaging 40 cm in height, were sourced from the nurseries at the Al-Hindiya station. A total of 480 seedlings of uniform size were planted in plastic pots with a diameter of 30 cm and a capacity of 10 kg. Standard agricultural practices were applied uniformly across all treatments.

The agricultural soil used for the seedlings was analyzed to determine its physical and chemical properties (Page *et al.*, 1982), with the results presented in Table 1. Sheep manure, collected from a private field, was also analyzed, and its characteristics are detailed in Table 2. The experiment followed a factorial arrangement (4×4) using a completely randomized design (CRD) with three replications. Each repetition consisted of 160 seedlings, with 10 seedlings per treatment. The study involved two factors: 1) four levels of potassium application (0, 10, 20, and 30 mg/L) and 2) four levels of organic matter (sheep manure) applied to the soil (0, 6, 12, and 18 tons per hectare), equivalent to 28.4, 56.8, and 85.2 grams per pot, respectively. Potassium was applied as a foliar spray, with the first application on April 15, 2023. A total of five sprays were planned, each spaced 30 days apart. However, due to high temperatures, only three sprays were completed by June 15, and the remaining two were carried out by September 15, 2023. The control treatment involved spraying distilled water on the plants. Irrigation was maintained consistently throughout the experiment. Manual spraying was conducted in the morning using a 2-liter handheld sprayer, ensuring adequate absorption by the seedlings (Gondal *et al.*, 2021).

Table 1: Some chemical and physical properties of soil were growing of seedlings

Traits	Values	Units
Sand	471.8	g/Kg soil
Silt	302.1	
Clay	226.1	
Texture	Loamy	
EC	2.87	dSm^{-2}
pH	7.5	
Total Nitrogen	51.3	mg/Kg
Available Phosphorous	10.4	
Available Potassium	13.6	
Organic Matter	0.81	g/Kg

Table 2: Chemical analysis of sheep manure

pH	Nitrogen	Phosphorus	Organic Matter	Total Carbon	Moisture	C/N
	g/Kg				%	
7.42	18.3	13.4	534.1	311.4	9.23	17.01

The experiment was concluded on November 15, 2023, as the temperature began to decrease, and no further significant growth was observed. Growth parameters including the height of the main stem (cm), diameter of the main stem (mm), total number of leaves per seedling, average leaf area (cm^2), average number of branches per seedling, and the dry matter percentage of both the vegetative and root systems were measured (Kirkby, 2023). At the end of the experiment, five seedlings were randomly selected from each replication of the experimental treatment for data collection and analysis.

Statistical Analysis

Samples were collected for analysis, and the data were statistically processed using Genstat software. To determine significant differences between means, the Least Significant Difference (LSD) test at the 0.05 level was applied (Al-Rawi & Khalaf Allah, 1980).

RESULTS AND DISCUSSION

Available Nitrogen, Phosphorus, and Potassium in the Soil after Cultivation (mg/kg)

Nitrogen content

The levels of potassium application significantly influenced the average available nitrogen content in the soil after cultivation, as shown in Table 3. The treatment with 20 mg/L potassium spray demonstrated the highest average nitrogen content of 68.40 mg/kg, outperforming the control treatment (spraying with distilled water), which yielded the lowest average of 56.33 mg/kg. Notably, the 30 mg/L potassium treatment did not show a significant difference compared to the control. Similarly, the addition of sheep manure at 18 tons per hectare significantly enhanced nitrogen availability, achieving the highest average of 69.73 mg/kg, compared to the control treatment, which resulted in the lowest average of 51.00 mg/kg (Table 3). Furthermore, the interaction between potassium spraying and manure application revealed distinct differences. The combination of 20 mg/L potassium and 18 tons/ha of sheep manure produced the highest average nitrogen content of 76.4 mg/kg, while the treatment without potassium spraying or manure addition resulted in the lowest average of 51.2 mg/kg.

Phosphorus content

The potassium levels in the soil also had a significant impact on the average available phosphorus content after cultivation.

Table 3: The effect of potassium spraying and the addition of organic matter on the soil's available N, P, and K

Potassium g/L	Organic Matter ton/h				Average
	Available N in the soil				
	0	6	12	18	
0	51.2	54.4	57.8	61.9	56.33
10	53.7	58.6	63.9	66.1	60.58
20	60.3	65.7	71.2	76.4	68.40
30	58.9	62.4	67.9	74.5	65.93
Average	51.00	60.28	65.20	69.73	
$LSD_{0.05}$	Potassium	Sheep manure			interaction
	3.07	3.07			6.14
	Available *P* in the soil				
Potassium g/L	0	6	12	18	Average
0	9.8	9.9	10.5	10.8	10.25
10	10.3	10.8	11.5	11.9	11.13
20	12.4	12.9	13.5	14.6	13.35
30	12.1	12.4	12.9	13.7	12.78
Average	11.15	11.50	12.10	12.75	
$LSD_{0.05}$	potassium	sheep manure			interaction
	0.58	0.58			1.16
	Available K in the soil				
Potassium g/L	0	6	12	18	Average
0	13.4	13.9	15.1	15.7	14.53
10	15.4	17.1	18.6	20.1	17.80
20	18.9	21.3	23.4	25.8	22.35
30	18.3	20.7	22.5	23.7	21.30
Average	16.50	18.25	19.90	21.33	
$LSD_{0.05}$	potassium	sheep manure			interaction
	1.16	1.16			2.32

The 20 mg/L potassium treatment performed exceptionally well, yielding the highest average phosphorus content of 13.35 mg/kg (Table 3). In contrast, the control treatment (spraying with distilled water) produced the lowest average of 10.25 mg/kg, with no significant difference observed at the 30 mg/L potassium level. The addition of sheep manure at 18 tons/ha also significantly improved phosphorus availability, achieving the highest average of 12.75 mg/kg, compared to the control treatment, which resulted in the lowest average of 11.15 mg/kg. The interaction highlighted that the combination of 20 mg/L potassium and 18 tons/ha of sheep manure exhibited superior results. Conversely, the treatment without potassium spraying or manure addition yielded the lowest average phosphorus content of 9.80 mg/kg.

In contrast, the combination treatment of 20 mg/L potassium spraying and 18 tons/ha sheep manure yielded the highest average phosphorus content of 14.60 mg/kg. This highlights the significant improvement in phosphorus availability when potassium and organic manure are applied together, compared to treatments where both were omitted.

Potassium content

The results for average available potassium in the soil (Table 3), indicated that the potassium application had a substantial impact. The treatment with 20 mg/L potassium spraying achieved the highest average potassium content of 22.35 mg/kg, significantly outperforming the control treatment (spraying with distilled water), which resulted in the lowest average of 14.53 mg/kg. The 30 mg/L potassium treatment showed no significant difference compared to the control.

Similarly, the addition of sheep manure at 18 tons/ha significantly enhanced potassium availability, producing the highest average of 21.33 mg/kg, compared to the control treatment, which yielded the lowest average of 16.50 mg/kg. The interaction treatment further emphasized the differences. The combination of 20 mg/L potassium spraying and 18 t/ha sheep manure delivered the highest average potassium content of 25.80 mg/kg, while the treatment without potassium spraying or manure addition resulted in the lowest average of 13.40 mg/kg. These findings demonstrated the critical role of potassium and organic manure in improving soil nutrient availability. The synergistic effect of combining potassium spraying with organic manure application significantly enhanced the availability of essential nutrients like phosphorus and potassium, which are vital for optimal plant growth and development. This highlights the importance of integrated nutrient management practices in agricultural systems to maximize crop productivity and soil health.

Correlation of soil analysis

The strong positive correlation between sheep manure and soil nitrogen (n), phosphorus (p), and potassium (k) indicates that adding manure significantly boosts these nutrients in the soil. The darker and larger circles suggest a high correlation (closer to +1), meaning manure is beneficial for soil fertility. The application of potassium helps retain or increase nitrogen levels. The significant correlation between phosphorus and potassium further supports the idea that potassium enhances overall soil nutrient balance.

Dim1 (75.6%) explains most of the variation in the data. The majority of variation in soil nutrient content is shown along this axis. Dim2 (21.5%) explains a smaller portion of the variation but still contributes to show the nutrients significance to each other. Soil Available Nitrogen (n) and Sheep Manure contribute the most to Dim1, highlighting their strong influence on soil composition. The addition of potassium is linked to higher soil potassium and phosphorus levels.

Average main stem length (cm)

Potassium levels in the soil had a significant effect on the average main stem length of the seedlings. The treatment with 20 mg/L potassium spray achieved the longest average stem length of 106.60 cm. In comparison, the control treatment (sprayed with distilled water) produced the shortest stems, with an average length of 89.40 cm, a value not significantly different from the 30 mg/L potassium treatment. The addition of 18 t/ha of sheep manure also resulted in improved stem length, with an average of 104.15 cm, which was notably higher than the control treatment average of 91.63 cm (Table 4).

The data further revealed significant differences between the various interaction combinations. The interaction treatment

Table 4: The effect of potassium spraying and the addition of organic matter on the stem height of pomegranate seedlings (cm)

Potassium g/L	Sheep manure (ton/h)				Average
	0	6	12	18	
0	82.3	85.4	92.8	97.1	89.40
10	85.1	87.4	91.5	98.6	90.65
20	100.7	104.5	108.9	112.3	106.60
30	98.4	102.5	103.7	108.6	103.30
Average	91.63	94.95	99.23	104.15	
$LSD_{0.05}$	potassium	sheep manure		interaction	
	3.37	3.37		6.74	

with no potassium spraying and no organic matter addition resulted in the shortest stem length, with an average length of 82.30 cm. On the other hand, the combination treatment of 20 mg/L potassium and 18 t/ha of sheep manure performed the best, producing the longest stems with an average of 112.30 cm.

The average number of leaves (leaves seedling^{-1})

The average number of leaves per seedling was significantly influenced by the application of potassium (Table 5). The highest average number of leaves (321.73 leaves) was observed in seedlings treated with a potassium spray concentration of 20 mg/L, indicating the optimal performance of this treatment. In contrast, the application of sheep manure at a rate of 18 t/ha yielded the lowest average number of leaves (285.50 leaves), which was statistically comparable to the results obtained with a 30 mg/L potassium spray. Notably, the control treatment, where seedlings were sprayed with distilled water, produced an average of 288.13 leaves, the lowest among all treatments.

Further analysis revealed significant variations among different interaction treatments. The combination of no potassium spray and no organic matter addition resulted in the lowest average leaf count (272.40 leaves). Conversely, the synergistic application of 20 mg/L potassium spray and 18 t/ha of sheep manure produced the highest average number of leaves (354.70 leaves), demonstrating the effectiveness of this combined treatment. These findings highlighted the substantial impact of potassium and organic matter interactions on seedling leaf development.

Average leaf area of a seedling (cm^2)

Potassium levels significantly influenced the average leaf area of the seedlings (Table 6). The most effective treatment involved spraying at a concentration of 20 mg/L, which yielded the highest average leaf area of 1540.23 cm^2. In contrast, the control treatment with distilled water, resulted in the lowest mean leaf area of 1006.23 cm^2, showing no significant statistical difference from the group treated with 30 mg/L. The application of sheep manure at a rate of 18 t/ha also demonstrated a notable improvement, producing an average leaf area of 1430.78 cm^2, which was significantly higher than the control treatment's average of 1149.63 cm^2.

Furthermore, the data highlighted the significant variation among different interaction treatments. The seedlings with no spray and no organic matter resulted in the lowest average leaf area of 889.40 cm^2. Conversely, the combined treatment of 20 mg/L potassium spray and 18 t/ha sheep manure application outperformed all others, achieving the highest average leaf area of 1696.40 cm^2. These findings underscore the importance of optimizing both potassium levels and organic matter application to enhance seedling growth and leaf area development.

Table 5: The effect of potassium spraying and the addition of sheep manure on the average number of leaves of pomegranate seedlings

Potassium g/L	Sheep manure (ton/h)				Average
	0	6	12	18	
0	272.4	283.5	289.4	296.7	285.50
10	285.4	296.2	307.5	315.8	301.23
20	300.1	308.5	323.6	354.7	321.73
30	294.6	305.4	317.8	341.4	314.80
Average	288.13	298.40	309.58	327.15	
$LSD_{0.05}$	potassium	sheep manure		interaction	
	8.34	8.34		16.68	

Table 6: The effect of potassium spraying and adding sheep manure on the average leaf area of pomegranate seedlings (cm^2)

Potassium g/L	Sheep manure (ton/h)				Average
	0	6	12	18	
0	889.4	944.3	1067.5	1123.7	1006.23
10	997.5	1107.4	1189.3	1278.4	1143.15
20	1407.5	1489.6	1567.4	1696.4	1540.23
30	1304.1	1366.5	1502.4	1624.6	1449.40
Average	1149.63	1226.95	1331.65	1430.78	
$LSD_{0.05}$	potassium	sheep manure		interaction	
	101.54	143.54		287.08	

Chlorophyll content in leaves

Potassium levels significantly influenced the chlorophyll content in the leaves (Table 7). The most effective treatment involved spraying at a concentration of 20 mg/L, which resulted in the highest average chlorophyll content of 43.30 SPAD. In comparison, the control treatment with distilled water, yielded the lowest mean chlorophyll content of 35.23 SPAD. The application of sheep manure at a rate of 18 t/ha proved to be highly effective, significantly outperforming the control treatment. While the control treatment produced an average chlorophyll content of 35.23 SPAD, the addition of sheep manure resulted in the highest average chlorophyll content of 43.35 SPAD.

Additionally, the data revealed notable differences among various interaction treatments. The seedlings without potassium spray and organic matter resulted in the lowest average chlorophyll content of 31.7 SPAD. In contrast, the combined treatment of 20 mg/L potassium spray and 18 t/ha sheep manure application achieved the highest average chlorophyll content of 47.10 SPAD. These findings highlighted the critical role of optimized potassium levels and organic matter application in enhancing chlorophyll content and, consequently, plant photosynthetic efficiency.

Table 7: The effect of potassium spraying and the addition of sheep manure on the average spad chlorophyll content of pomegranate seedlings

Potassium g/L	Sheep manure (ton/h)				Average
	0	6	12	18	
0	31.7	34.2	36.9	38.1	35.23
10	32.5	34.9	38.1	42.5	37.00
20	39.4	42.5	44.2	47.1	43.30
30	37.8	40.2	43.8	45.7	41.88
Average	35.35	37.95	40.75	43.35	
$LSD_{0.05}$	potassium	sheep manure		interaction	
	1.65	1.65		2.30	

Table 8: The effect of potassium spraying and the addition of sheep manure on the average dry weight of the shoot of pomegranate seedlings (g)

Potassium g/L	Sheep manure (ton/h)				Average
	0	6	12	18	
0	29.5	32.4	35.1	38.9	33.98
10	33.4	37.8	39.5	42.1	38.20
20	35.6	42.1	45.8	48.2	42.93
30	35.3	41.9	44.6	46.1	41.98
Average	33.45	38.55	41.25	43.83	
$LSD_{0.05}$	potassium	sheep manure		interaction	
	1.69	1.69		3.38	

Average dry weight of shoot (g)

Potassium levels significantly influenced the average dry weight of the shoot (Table 8). The most effective treatment involved spraying at a concentration of 20 mg/L, which yielded the highest average dry weight of 42.93 g. In contrast, the control treatment with distilled water produced the lowest mean dry weight of 33.98 g, showing no significant difference from the treatment with 30 mg/L. The application of sheep manure at a rate of 18 t/ha^{-1} also demonstrated remarkable effectiveness, surpassing expectations. This treatment resulted in the highest average dry weight of 43.83 g, significantly outperforming the control treatment, which had the lowest average of 33.45 g.

Furthermore, the data revealed notable differences among various interaction treatments. The combination of 20 mg/L potassium spray and 18 t/ha^{-1} sheep manure application excelled, producing the highest average dry weight of vegetative growth at 48.20 g. Conversely, the interaction treatment with no potassium spraying and no organic matter addition resulted in the lowest average dry weight of 29.50 g. These findings emphasize the importance of optimizing potassium levels and organic matter application to enhance vegetative growth and dry matter accumulation in plants.

Average root system dry matter (g)

Potassium levels significantly influenced the average dry matter of the root system (Table 9). The spraying treatment at a concentration of 20 mg/L demonstrated exceptional performance, producing the highest average root dry matter of 12.13 g. In comparison, the control treatment, which involved spraying with distilled water, resulted in the lowest mean of 8.43 g and showed no significant statistical difference from the treatment with 30 mg/L. The addition of sheep manure at a rate of 18 t/ha also led to a substantial improvement in root dry matter. This treatment yielded the highest average of 13.68 g, significantly outperforming the control treatment, which had the lowest average of 7.48 g.

Additionally, the data revealed distinct differences among various interaction treatments. The seedlings with no potassium spraying and sheep manure, resulted in the lowest average root dry matter of 6.30 g. Conversely, the combination treatment of 20 mg/L potassium spray and 18 t/ha sheep manure application excelled, producing the highest average root dry matter. These

Table 9: The effect of potassium spraying and the addition of sheep manure on the average dry weight of the root system of pomegranate seedlings (g)

Potassium g/L	Sheep manure (ton/h)				Average
	0	6	12	18	
0	6.3	6.9	9.8	10.7	8.43
10	7.1	7.8	10.5	11.8	9.30
20	8.4	10.9	12.7	16.5	12.13
30	8.1	9.4	12.3	15.7	11.38
Average	7.48	8.75	11.33	13.68	
$LSD_{0.05}$	potassium	sheep manure		interaction	
	2.38	2.38		4.76	

findings underscore the critical role of optimized potassium levels and organic matter application in enhancing root system development and dry matter accumulation.

After the plantation of seedlings, the application of 18 t/ha of organic fertilizer significantly increased the availability of nitrogen, phosphorus, and potassium in the soil (Table 3). Organic fertilizers serve as a fundamental source of nutrients, facilitating the release of essential elements and making them readily available in the soil solution. Among the nutrient reserves in organic matter, carbon and nitrogen are the most abundant, followed by phosphorus, iron, and sulfur. The release of hydrogen from carboxylic groups in organic matter helps maintain optimal soil buffering capacity. Additionally, organic matter competes with phosphate ions on soil particles. The negative charge of humus in organic matter further reduces phosphorus retention by chelating iron, aluminum, and calcium ions. Moreover, the decomposition of organic matter releases CO_2, which forms carbonic acid in the soil solution, dissolving phosphate compounds and enhancing phosphorus availability (Al-Azzawi, 2010).

Addition of sheep manure and potassium significantly improved the growth indicators of Selimi pomegranate seedlings (Tables 4-9). The addition of 18 t/ha of organic matter led to notable increases in the length of the seedlings, stem diameter, leaf number, leaf area, chlorophyll content, branch number, total shoot dry weight, and total root dry weight. These improvements are likely due to sheep manure, which contains organic acids that enhance cellular membrane permeability and nutrient transport within the plant. It promotes cell elongation, division, and overall vegetative growth (Judy, 2012; Mansour, 2018). Furthermore, organic fertilizers are rich in humic and fulvic acids, provide a high nitrogen content that boosts carbohydrate storage, photosynthetic efficiency, and vegetative growth (Al-Ahbabi, 2011). Humic acids also improve nutrient absorption, particularly for micronutrients, and increase phosphate availability by binding to phosphate ions (Khodair & El-Rahman, 2021). Additionally, humic acids reduce IAA oxidase activity, increasing auxin (IAA) levels, which stimulate root development and plant growth while enhancing soil nutrient retention (Moustafa *et al*., 2016). The application of humic acid also improves plant tolerance to drought and high temperatures by regulating osmotic pressure, respiration, protein metabolism, and stomatal function (Chen *et al*., 2022).

Potassium foliar application further enhanced the growth characteristics of pomegranate seedlings. Although potassium does not directly contribute to cell structure, it is essential for plant growth and development. It activates enzyme systems involved in cell division, protein synthesis, nucleic acid formation, and photosynthesis, all of which promote plant height and vegetative dry weight (Radhi & Alkarawia, 2021; Brown *et al*., 2022; Poirier *et al*., 2022). Potassium also stimulates root system growth, improves nutrient uptake (particularly nitrogen and phosphorus), and enhances leaf surface area, increasing CO_2 availability for photosynthesis and carbohydrate production. Additionally, potassium plays a role in ATP formation, which is critical for transporting photosynthetic products and synthesizing high-molecular-weight compounds like carbohydrates and proteins, thereby increasing plant dry weight (Kirkby, 2023). The application of potassium also boosted photosynthetic efficiency, leading to increased leaf number, leaf area, and overall plant metabolism, as well as higher flower and inflorescence production.

Sulfur, another essential nutrient, plays multiple roles in plant growth. It is involved in the synthesis of amino acids such as methionine and cystine, which are precursors to protein formation. Sulfur also participates in oxidation-reduction reactions, energy metabolism, and the decarboxylation of pyruvic acid to form active acetate, a key component of the Krebs cycle in respiration (Dhal & Pal, 2022). These processes underscore the importance of sulfur-containing compounds in plant growth and development.

Correlation, Heat Map and Principal Component Analysis

Correlation

The correlation matrix explains different factors, such as sheep manure, potassium, and seedling growth parameters related to each other as reported by Zafar *et al.* (2015) (Figures 1 & 2). Strong positive correlations exist between sheep manure and key growth indicators suggesting that sheep manure enhances soil nutrients, leading to healthier seedlings (Figure 3). Potassium application shows a strong positive correlation indicating that it helps seedlings grow taller and develop stronger roots and shoots, due to its role in nutrient absorption and photosynthesis. Leaf chlorophyll content is positively correlated with average

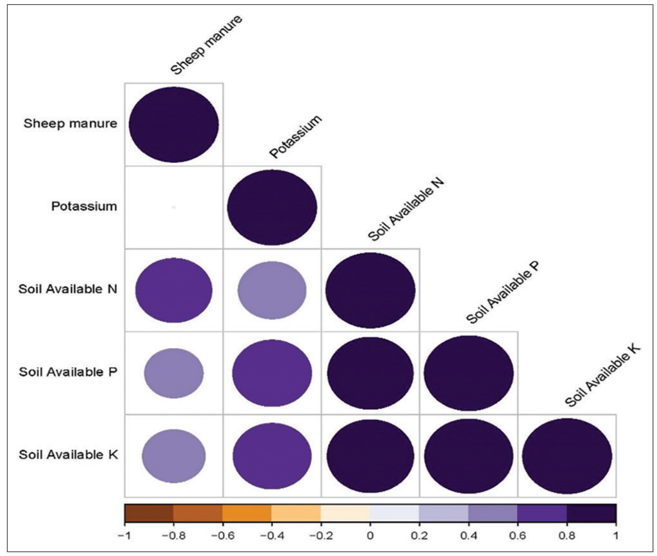

Figure 1: The correlation matrix shows the relationship between sheep manure, potassium, and seedling growth

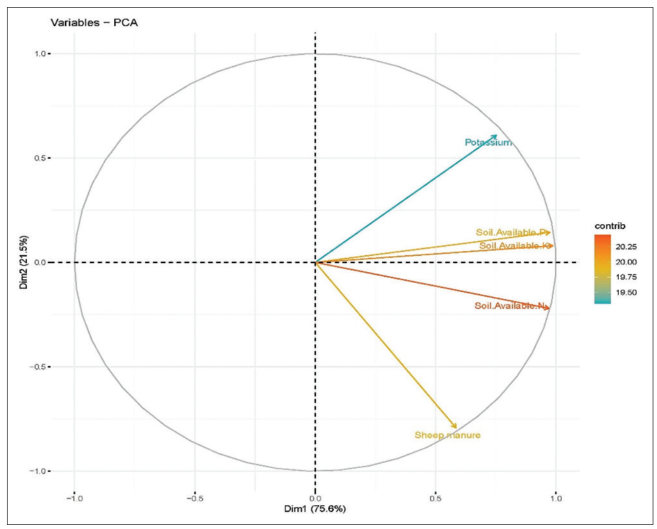

Figure 2: The correlation between soil analysis and the addition of potassium reveals a link to higher soil potassium and phosphorus levels

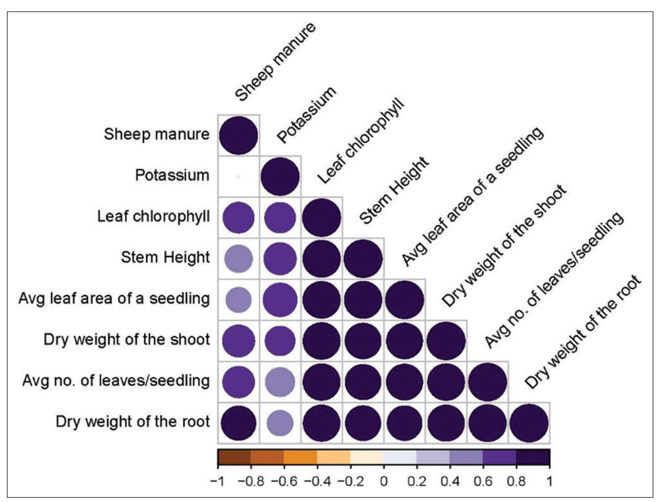

Figure 3: Correlation showing the effect of foliar spraying of potassium and sheep manure application on growth traits of pomegranate seedlings

leaf area, stem height, and shoot dry weight. This suggests that healthier leaves with more chlorophyll support overall plant growth. Stem height is strongly correlated with the dry weight of shoots and roots, meaning taller plants generally have better biomass accumulation. The average number of leaves per seedling is positively linked to other growth factors, confirming that healthier plants produce more leaves. Further, combining organic manure with potassium spraying enhances overall plant health.

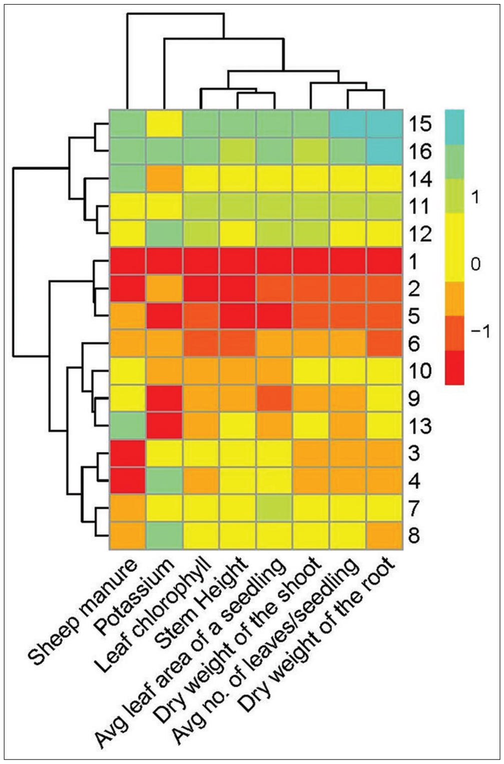

Figure 4: Heat map showing the effect of foliar spraying of potassium and sheep manure application on growth traits of pomegranate seedlings

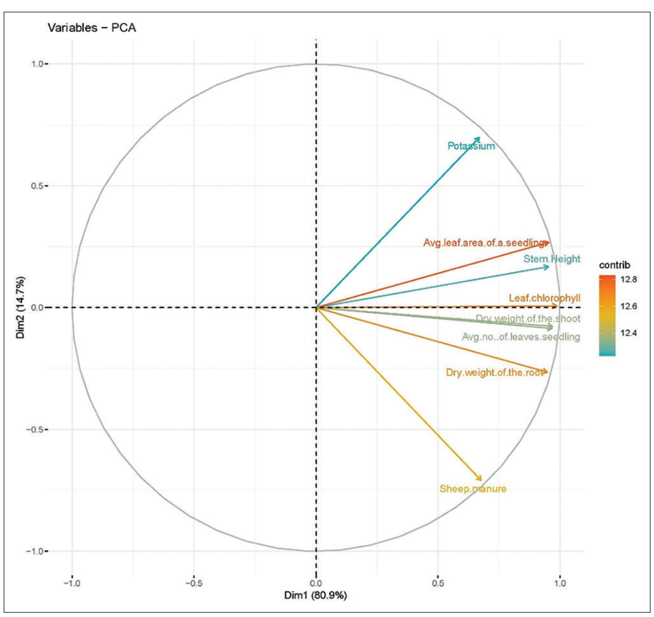

Figure 5: Principal component analysis showing the effect of foliar spraying of potassium and sheep manure application on growth traits of pomegranate seedlings

Heat map

The green, yellow and cyan color in the heatmap shows strong positive relationships between sheep manure, potassium, and various growth indicators like stem height, dry weight, and leaf area (Figure 4). The red or orange colors in the heat map represent a weak correlation between parameters Zafar *et al.* (2019).

Principal component analysis

The principal Component Analysis (PCA) biplot further explains different seedling growth factors with sheep manure and potassium application. Dim1 (X-axis) explains 80.9% of the variation in factors, Dim2 (Y-axis) is contributes 14.7% of the variation (Figure 5). Potassium is strongly associated with leaf chlorophyll, stem height, and average leaf area, indicating its role in improving photosynthesis, growth, and leaf development. Sheep manure is strongly linked to the dry weight of the root, suggesting its role in improving root biomass and soil nutrient availability. The dry weight of the root has a strong link with sheep manure, but it is not as closely related to potassium's influence suggesting that sheep manure primarily benefits root growth, while potassium enhances above-ground growth (Zafar *et al.*, 2019)

CONCLUSIONS AND RECOMMENDATIONS

The addition of organic matter (sheep manure) and potassium spraying significantly improved the growth and development of pomegranate seedlings. The application of 18 tons/ha of sheep manure enhanced key growth indicators, particularly due to the presence of organic acids and nutrients. Additionally, potassium spraying, particularly at a concentration of 20 mg/L, played a crucial role in promoting plant growth by enhancing cell division, photosynthesis, and nutrient absorption. The combined application of organic matter (sheep manure) and potassium spraying significantly enhanced the growth and development of pomegranate seedlings by improving nutrient availability, photosynthetic efficiency, and overall plant metabolism. These findings highlighted the importance of optimizing organic and inorganic fertilization practices to maximize plant growth and productivity.

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NOVELTY STATEMENT

This study introduces a novel approach in using sheep manure and potassium spraying as fertilizer on the growth and development of pomegranate seedlings. Their synergistic application significantly enhanced growth indicators such as stem length, leaf area, chlorophyll content, and overall biomass.

The findings provide valuable implications for improving pomegranate cultivation practices, emphasizing the potential benefits of integrated fertilization strategies in promoting sustainable and high-quality fruit production.

AUTHORS' CONTRIBUTION

MTA, GAA, and HHA conceived and designed the research, conducted the experiments, and collected the data. HHA and SLA assisted in data analysis and interpretation, contributing to methodology refinement and laboratory supervision. MTA, GAA, HHA, and SLA drafted the manuscript. All authors read and approved the final version of the manuscript.

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