

Effectiveness of nano-mixture Fertilize on growth and yield of *Vicia faba* under water stress

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Abstract

A field experiment was conducted during the winter season of 2025–2026 in a private field located in Al-Azaziya area, Al-Musayyib District, 40 km north of Babylon Governorate, with the aim of investigating the effect of water stress levels and the role of foliar application of a nano-mixture of potassium and graphene on the growth and yield of faba bean (*Vicia faba* L.). The experiment was arranged in a split-plot design according to a Randomized Complete Block Design (RCBD) with three replicates. The experiment included two factors: the first, assigned to the main plots, comprised three water stress levels — 40%, 60%, and 80% depletion of field capacity; the second factor, assigned to the subplots, comprised three concentrations of the nano-mixture of potassium and graphene, namely 0.05, 0.10, and 0.15 ml·L⁻¹, in addition to a control treatment of distilled water spray only.

The results showed that the 40% water stress level significantly outperformed other levels, recording the highest means for plant height and number of branches, reaching 105.17 cm and 10.85 branches·plant⁻¹, respectively. The 80% water stress level recorded the highest proline content in leaves, reaching 3.089 μmol·g⁻¹ FW. With regard to yield indicators, the 40% stress level produced the highest means for number of pods per plant, number of seeds per pod, and total dry grain yield, which reached 26.67 pods·plant⁻¹, 5.32 seeds·pod⁻¹, and 3.438 Mg·ha⁻¹, respectively.

The nano-mixture concentration of 0.10 ml·L⁻¹ significantly surpassed other concentrations, recording the highest means for plant height and number of branches, reaching 103.27.83 cm and 11.06 branches·plant⁻¹, respectively. The same concentration also recorded the highest mean for leaf proline content at 2.648 μmol·g⁻¹ FW, and outperformed in yield traits including number of pods per plant, number of seeds per pod, and total dry seed yield, which reached 24.78 pods·plant⁻¹, 5.071 seeds·pod⁻¹, and 3.142 Mg·ha⁻¹, respectively.

Keywords: Faba bean, Water stress, Nano-potassium, Nano-graphene

1- Introduction

Faba bean (*Vicia faba* L.) is one of the most important legume crops widely cultivated in many countries around the world, owing to its high nutritional value and significant role in achieving food security.

Faba bean also plays a vital environmental role in improving soil fertility through its ability to fix atmospheric nitrogen via root nodules that form a symbiotic relationship with *Rhizobium* bacteria, converting it into a form that can be absorbed by the plant,

thereby improving the agricultural properties of the soil and increasing its fertility [1].

Water stress is considered one of the most prominent challenges facing faba bean cultivation, particularly in arid and semi-arid regions that suffer from fluctuating rainfall rates and scarce water resources. Water stress negatively affects numerous physiological and vital processes in the plant, as it leads to inhibition of vegetative growth, reduced stem elongation rates, weakened enzymatic activity, decreased cell division, as well as causing damage to cell membranes and cell walls [2].

With the remarkable advances in nanotechnology, the possibility of using nutrients in nano-forms has emerged with the aim of increasing the plant's efficiency in utilizing nutrients, thereby contributing to improved growth, increased productivity, and enhanced crop quality. Nanoparticles are considered physiological stimulants that contribute to improving plant growth and regulating nutrient uptake, which helps plants cope with deficit irrigation conditions and reduce the harmful effects resulting from drought and disease. This is due to their high penetration ability and large surface area, which increases the contact area with plant tissues, leading to enhanced growth and improved production [3].

Potassium is one of the most important elements due to its vital role in numerous biochemical and physiological processes within the plant. Potassium contributes to the activation of a large number of enzymes and proteins, and participates in regulating photosynthesis and carbohydrate metabolism, in addition to its important role in regulating osmotic balance, stomatal movement, and maintaining ionic equilibrium within plant cells. Potassium also plays an essential role in energy transfer and the transport of plant

sap. These vital functions collectively contribute to enhancing the plant's ability to tolerate unfavorable environmental conditions, particularly water stress, by improving water use efficiency and maintaining the plant's physiological processes under drought conditions [4].

Graphene is considered one of the modern nanomaterials; it consists of two-dimensional crystals of atomic thickness, composed of a single layer of carbon atoms bonded together by strong and regular covalent bonds, forming a hexagonal lattice structure known as the graphene compound [5]. Graphene is distinguished by unique physical and chemical properties, such as its high surface area, great electrical and thermal conductivity, as well as its high mechanical strength. Therefore, this study aimed to investigate the role of a nano-mixture of graphene and potassium in reducing the harmful effects of water stress on the faba bean crop.

2- Materials and Methods

The experiment was conducted in a private field in the Al-Azaziya area / Al-Musayyib district, 40 km north of the center of Hilla city in Babylon Governorate, at longitude 44.5° and latitude 32.7° N, during the 2025–2026 growing season. The designated soil was prepared at the beginning of September by clearing it of the previous crop residues. The experimental land was then plowed with two perpendicular tillage passes, followed by laser leveling to achieve a uniform and even surface. The field soil was planted on 28/9/2025 by placing two seeds in each hole, and after germination, the seedlings were thinned to one plant per hole. Hoeing and weed control were carried out manually on a continuous basis as needed. The land was then divided into three replicates.

A field experiment was applied using a Randomized Complete Block Design (RCBD) arranged in a split-plot arrangement with three replicates. The experiment included the study of two factors: the first was three soil moisture levels (40%, 60%, and 80%) depletion of field capacity; and the second was a nano-mixture of 50% graphene and 50% potassium at four concentration levels of (0, 0.05, 0.10, and 0.15) ml, respectively.

The experimental treatments were sprayed twice: the first at the four-leaf stage and the second at the beginning of the flowering stage. Water stress treatments were assigned to the main plots and nano-mixture application treatments to the sub-plots, separated by a 2-meter distance to serve as service pathways for crop management. Each block was then divided into 12 experimental units, separated from one another by a distance of 1.5 meters to prevent water seepage between units. To prevent the drift of nano-fertilizer spray concentrations between treatments, agricultural nylon barriers were used. Spraying was carried out in the early morning using a 16-liter backpack sprayer operating by a pressurized charging mechanism to maintain constant spray pressure. To ensure the maintenance of the designated water stress levels and to prevent rainfall from affecting the experimental results, agricultural nylon sheets were

mounted on reinforced wooden frames and used as protective covers over the experimental units subjected to water stress treatments during rainfall events. These covers were removed immediately after the rainfall ceased. This procedure prevented rainwater from reaching the plants and maintained the predetermined soil moisture levels for each treatment, thereby ensuring accurate application of water stress treatments and minimizing the influence of uncontrolled environmental factors on the experimental outcomes.

Treatments were then randomly distributed across the experimental units, bringing the total number of experimental units to 36, with each experimental unit covering an area of $2 \times 2 \text{ m}^2$, containing 5 furrows. Planting was carried out on one side of each furrow, with a spacing of 30 cm between holes within the furrow and 40 cm between furrows.

The relationship between the matric potential of the field soil sample and its moisture content was determined in order to estimate the soil's water retention capacity, whereby different matric potentials of 33, 100, 300, 500, and 1500 kPa were applied. The relationship was represented graphically in the soil moisture retention curve (Figure 1). The available water content of the soil was calculated from the difference in moisture content between field capacity and the wilting point [6].

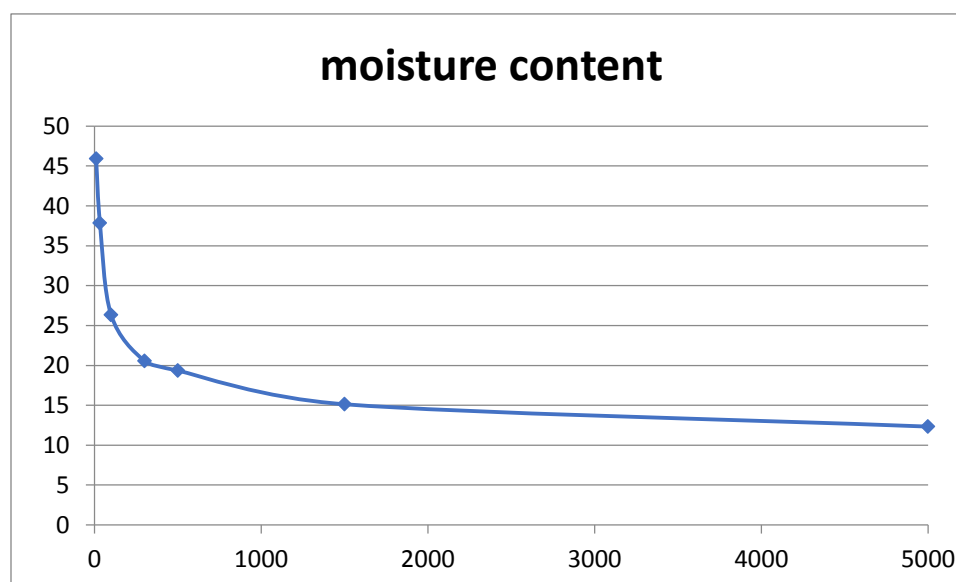


Figure 1. Soil moisture characteristic curve of the soil used in the experiment

2-1- Irrigation Method:

Irrigation was carried out using plastic pipes connected to an electric pump with a constant discharge rate. A water meter was installed on the pipe to measure the volume of water passing through it in liters. Equal amounts of water were added to all plots at planting (the first irrigation) up to field capacity to ensure uniform field germination.

Monitoring Depletion and Measuring Soil Moisture Content:

Soil moisture content was continuously monitored and measured on a near-daily basis using the gravimetric method for field soil moisture measurement. Soil samples were taken from the experimental units (treatments) at various depths ranging from 0–0.4 m, dried at a temperature of 105°C for 24 hours, and the moisture percentage was calculated according to the following equation [6]:

2-2- Preparation of the Nano-Mixture

Three concentrations of the nano-mixture (50% potassium with 50% graphene) were prepared as follows:

The first concentration consisted of 0.05 ml graphene with 0.05 ml potassium with 75 ml of distilled water in a flask. The sample was then placed in a Magnetic Stirrer at a temperature of 70–75°C for 30 minutes. Finally, the mixture was placed in a container, sealed tightly, and put in a water bath at a temperature of 40–50°C for 30 minutes.

Using the same method, the second concentration was prepared consisting of 0.10 ml graphene with 0.10 ml potassium with 75 ml of distilled water, and the third concentration consisting of 0.15 ml graphene with 0.15 ml potassium with 75 ml of distilled water.

2-3- Studied Traits

2-3-1- Plant Height (cm)

Plant height was measured using a measuring tape from the point of contact

of the plant with the soil surface to the plant apex. The average measurement of five plants randomly selected from the middle rows of each experimental unit was recorded [8].

2-3-2- Number of Branches per Plant (branch plant⁻¹)

The number of branches per plant was calculated as the mean of five randomly selected plants.

2-3-3- Leaf Proline Amino Acid Content (μmol g⁻¹)

To measure the proline content in leaves subjected to water stress, the method adopted by [9] was followed.

2-3-4- Number of Pods per Plant (pod plant⁻¹)

The number of pods was counted for five plants and divided by the number of plants, and their mean was recorded.

2-3-5- Number of Seeds per Pod (seed pod⁻¹)

The number of seeds in the pods of five plants was counted and their mean was calculated.

2-3-6- Dry Seed Yield (Mg ha⁻¹)

This was estimated from the yield of the two inner furrows and extrapolated to a unit area basis.

2-4- Statistical Analysis

Statistical analysis was carried out according to the Randomized Complete Block Design in a split-plot arrangement using the GenStat 12 statistical software. Means of the studied treatments were compared using the Least Significant Difference (LSD) test at a probability level of 5% [10].

3-Results

1. Results of Vegetative and Physiological Traits

Table (3) shows that the main effects of the study factors and their interaction significantly influenced plant height, number of branches, and leaf proline content. The 40% stress level recorded the highest mean values for plant height and number of branches, reaching 105.17 cm and 10.85 branches plant⁻¹, respectively. In contrast, the 80% stress level resulted in the highest leaf proline content, with a mean value of 3.089 μmol g⁻¹ fresh weight, compared with the 40% stress level, which recorded the lowest mean value of 1.534 μmol g⁻¹ fresh weight.

The results further indicate that the application of the graphene–potassium

nanocomposite at a concentration of 0.10 mL significantly outperformed the other treatments, producing the highest mean values of plant height, number of branches, and leaf proline content, reaching 103.27 cm, 11.06 branches plant⁻¹, and 2.648 μmol g⁻¹ fresh weight, respectively. These values were significantly higher than those obtained from the control treatment (sprayed with distilled water only), which recorded the lowest mean values of 82.02 cm, 6.00 branches plant⁻¹, and 2.038 μmol g⁻¹ fresh weight for the respective traits.

The interaction treatment between the graphene–potassium nanocomposite concentration of 0.10 mL and the 40% stress level significantly increased plant height and number of branches,

producing the highest mean values of 110.83 cm and 13.23 branches plant⁻¹, respectively. These values were significantly greater than those recorded for the interaction treatment of 0.00 mL

nanocomposite concentration and 80% stress level, which produced the lowest mean values of 65.20 cm and 5.07 branches plant⁻¹, respectively.

Table (1). Effect of stress levels and foliar application of graphene–potassium nanocomposite on selected vegetative and physiological traits.

Proline contant on Leaf (μmol.g ⁻¹ fresh weight)	Number of Branches per Plant (branch.plant ⁻¹)	Plant Height (cm)	Treatment	
1.534	10.85	105.17	40	Stress Levels (%)
2.500	8.28	94.92	60	
3.089	6.67	81.31	80	
0.0666	1.151	7.20	L S D (0.05)	
2.038	6.00	82.02	0.00	Graphene Potassium Concentrations (mL)
2.399	7.23	90.19	0.05	
2.648	11.06	103.27	0.10	
2.412	9.94	99.72	0.15	
0.1024	1.322	3.81	L S D (0.05)	
1.559	7.00	97.87	0.00	%40
1.747	10.67	106.43	0.05	
1.521	13.23	110.83	0.10	
1.310	12.50	105.57	0.15	
2.533	6.23	83.00	0.00	%60
2.446	6.03	87.10	0.05	
2.567	10.07	107.30	0.10	
2.454	10.77	102.27	0.15	
2.021	5.07	65.20	0.00	%80

3.005	5.17	77.03	0.05	
3.857	9.87	91.67	0.10	
3.472	6.57	91.33	0.15	
0.1601	2.265	8.07	L S D (0.05)	

4. Results of Yield and Yield Components

The results presented in Table (4) reveal significant effects of the study factors and their interaction on the number of pods per plant, number of seeds per pod, and dry seed yield. The 40% stress level recorded the highest mean values for these traits, reaching 26.67 pods plant⁻¹, 5.320 seeds pod⁻¹, and 3.438 Mg ha⁻¹, respectively. In contrast, the 80% stress level resulted in the lowest mean values of 13.92 pods plant⁻¹, 3.238 seeds pod⁻¹, and 1.990 Mg ha⁻¹, respectively.

The same table also demonstrates that grapheme – potassium nanocomposite concentration of 0.10 mL significantly enhanced all yield-related traits, producing the highest mean values of 24.78 pods plant⁻¹, 5.071 seeds pod⁻¹, and 3.142 Mg t ha⁻¹, respectively.

These values were significantly superior to those obtained from the control treatment (distilled water spray only), which recorded the lowest mean values of 14.72 pods plant⁻¹, 3.330 seeds pod⁻¹, and 2.058 Mg ha⁻¹, respectively.

Furthermore, the interaction between grapheme – potassium nanocomposite concentration of 0.10 mL and the 40% stress level produced the highest values for number of pods per plant, number of seeds per pod, and total seed yield, reaching 32.67 pods plant⁻¹, 6.567 seeds pod⁻¹, and 4.073 Mg ha⁻¹, respectively. Conversely, the interaction treatment between the 0.00 mL nanocomposite concentration and the 80% stress level recorded the lowest values of 11.00 pods plant⁻¹, 2.677 seeds pod⁻¹, and 1.437 Mg ha⁻¹ for the same traits, respectively.

Table (2). Effect of stress levels and foliar application of graphene–potassium nanocomposite on yield and its components.

Dry Grain Yield (ton.ha ⁻¹)	Number of Seeds per Pod (seed.pod ⁻¹)	Number of Pods per Plant (pod.plant ⁻¹)	Treatment	
3.438	5.320	26.67	40	Stress Levels (%)
2.768	4.213	20.46	60	
1.990	3.238	13.92	80	
0.1183	0.3573	4.258	L S D (0.05)	
2.058	3.330	14.72	0.00	Graphene Potassium Concentrati ons (mL)
2.695	3.932	18.44	0.05	
3.142	5.071	24.78	0.10	
3.034	4.696	23.44	0.15	
0.1547	0.4551	2.333	L S D (0.05)	
2.281	3.977	20.00	0.00	%40
3.580	4.403	24.00	0.05	
3.819	6.567	32.67	0.10	
4.073	6.333	30.00	0.15	
2.455	3.337	13.17	0.00	%60
2.652	4.393	17.33	0.05	
2.880	5.210	26.67	0.10	
3.087	3.913	24.67	0.15	
1.437	2.677	11.00	0.00	%80
1.854	3.000	14.00	0.05	
2.727	3.437	15.00	0.10	
1.941	3.840	15.67	0.15	
0.2458	0.7253	4.840	L S D (0.05)	

4-Discussion

4-1 - Discussion of the Effect of Water Stress on Vegetative Growth, Physiological Traits, Yield, and Its Components:

Faba bean is considered one of the most drought-sensitive crops compared to other crops, and the decline in production is directly linked to the amount of available water. This study confirms the necessity of prioritizing the identification of nutrients that can increase faba bean resistance to drought stress.

The results of this study indicated that water stress caused a reduction in plant height due to the inability of cells to divide, differentiate, and elongate to produce greater stem height, in which the maximum amount of dry matter that the plant can benefit from in subsequent growth stages when translocated to sink organs is accumulated. This may also result in a higher number of branches, which is ultimately reflected in yield components. These results are consistent with the findings of both [11] and [12], who confirmed that water stress directly or indirectly affects most vegetative growth traits, including plant height and number of branches in faba bean.

The study results also show that leaf proline content accumulation increased under stress conditions and decreased under normal irrigation. This inverse relationship has been found in many studies, and its cause is that elevated proline in leaf tissue leads to the regulation of osmotic potential to avoid dehydration and to balance water absorption. Proline is also considered a source of respiratory energy for the plant under severe drought stress conditions

and is released as a defense mechanism [13]. It was also found that water stress had a positive effect on leaf proline content, which was more pronounced at the high water stress level of 80% of field capacity, as proline accumulation in plant leaves contributes to reducing the toxic effects of ions on enzyme activity and limits the formation of free radicals resulting from drought stress [14].

The results of Tables 4, 5, and 6 for the traits of number of pods, number of seeds per pod, and grain yield indicate that exposure of faba bean plants to water deficit during the vegetative growth stage negatively affects yield traits and their components. The various effects of water stress on reproductive traits present significant challenges in resource distribution within the plant under deficit irrigation conditions. Furthermore, fertilization failure leads to a reduction in the number of seeds per pod, which is one of the most important yield components that determines the final seed yield and is difficult to compensate for through other components when a reduction occurs [15].

In the current experiment, it was found that yield, based on the obtained results represented by the number of pods and number of seeds per pod, decreased with increasing water stress intensity in the 60% and 80% field capacity treatments. This may be attributed to the decline in plant growth indicators, including the inhibition of cell elongation and division, which reduced the processes of dry matter formation associated with metabolic processes, and this was consequently reflected in seed yield.

4-2- Discussion of the Role of Nano-Mixture Foliar Spraying on Vegetative Growth Traits, Yield, and Its Components

The current study indicated that foliar spraying with potassium leads to a significant increase in plant height and number of branches. This is attributed to the role of the nano-mixture in improving cell division and elongation, in addition to its contribution to the formation and development of chloroplasts, which works to increase the efficiency of carbon assimilation. The improvement that occurred in the growth traits of the faba bean crop resulted from the foliar application of the nano-mixture of potassium and graphene, as they work together to reduce the damage of water stress, particularly during the grain filling and elongation stage, and their relation to nutrient accumulation in seeds. Potassium accelerates the movement of these elements from leaves to reproductive parts, and also increases chlorophyll synthesis, which raises the proportion of metabolic products entering the seeds, and this is reflected in the yield [16].

Seed yield increased significantly when using the nano-mixture of potassium and graphene at a concentration of 0.10 ml, and this can be considered a precise indicator that can be used to reduce the damage of water stress on the faba bean crop. In general, it can be said that foliar spraying with the nano-mixture is an effective means of improving the vegetative growth traits of the faba bean crop by enhancing the vital and physiological processes of the plant, increasing photosynthetic efficiency, and

improving water and nutritional balance, which is positively reflected in crop growth vigor and its ability to tolerate various environmental conditions, as well as benefiting from potassium during the stages in which the plant is unable to provide the basic requirements for transitioning to the reproductive stage [17].

The results indicate that foliar spraying with concentrations of nano-potassium and graphene led to an increase in dry seed yield in faba bean, and that this increase occurred due to the increase in the number of pods per plant as well as the number of seeds per pod, which was reflected in grain yield. These results are consistent with what was indicated by [18], and the reason for this increase may be attributed to the improvement in vegetative growth indicators, followed by an improvement in the efficiency of transferring carbon assimilation products to the economic part of the crop, most importantly the yield components [18].

It was also mentioned by [19] that foliar spraying with graphene is considered one of the best application treatments, which increased plant height and number of branches. They also confirmed that the use of graphene oxide at reduced concentrations positively improves the growth traits of the crop. Furthermore, its low concentrations help in the adsorption of macroelements, most importantly nitrogen and potassium, and work to regulate enzyme activity and help increase water absorption to maintain the required balance within leaf cells [20].

When considering these reasons and other factors that have made nano foliar spraying of potassium and graphene one

of the field practices that can reduce the damage of water stress in the medium and long term, and increase water absorption efficiency through their action in enhancing the activity of antioxidant enzymes and stimulating cell division, which improves the physiological traits of the faba bean crop.

5- Recommendations

1- The use of water stress higher than 40% of field capacity may not significantly affect the growth traits and yield of the faba bean crop within certain limits, particularly when spraying with the nano-mixture of potassium and graphene.

2- Spraying the nano-mixture of potassium and graphene at concentrations higher than 0.15 ml may not further increase yield, as observed from the study results, and may potentially have a toxic effect on the crop.

3- We recommend the use of this mixture on different crops, as it has not been widely used, and at growth stages other than those covered in the current study.

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