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The effect of Nano NPK and Compost Fertilization on growth, physiological performance and nutrient use efficiency in two Faba Bean (*Vicia faba* L.) varieties

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تأثير التسميد بالنانو *NPK* والكمبوست على النمو، الأداء الفيزيولوجي، وكفاءة استخدام العناصر الغذائية في صنفين من الفول البلدي (*Vicia faba L.*)

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Abstract:
Improving nutrient use efficiency through integrated fertilization management represents a promising approach to enhance faba bean production under semi-arid agro-ecosystems. Therefore, a field experiment was conducted in the Wadi Atbah region of southern Libya during the 2025/2026 growing season to evaluate the efficacy of Nano NPK fertilizer and compost, applied individually or in combination, on the physiological performance and nutrient use efficiency of two faba bean (Vicia faba L.) cultivars. The experiment was laid out in a randomized complete block design (RCBD) featuring seven fertilization treatments and three replications. Leaf water content, SPAD chlorophyll values, relative growth rate (RGR), along with nitrogen (N), phosphorus (P), and potassium (K) use efficiencies, were systematically determined. The results revealed that fertilization treatments, cultivar types, and their interactions exerted highly significant effects on all measured traits ($P < 0.001$). Among the fertilization strategies, the combined application of Nano NPK and compost (T7) proved superior, recording the highest leaf water content, SPAD values, RGR, and nutrient use efficiencies, followed by the combination of 50% Nano NPK and 50% mineral NPK (T5) and mineral NPK combined with compost (T6), whereas the control treatment (T1) exhibited the lowest performance. Compared with the control, treatment T7 enhanced leaf water content, SPAD, RGR, NUE, PUE, and KUE by 28%, 26%, 31%, 31%, 29%, and 31%, respectively. Furthermore, the imported cultivar outperformed the local cultivar across all evaluated parameters. The enhanced physiological performance and nutrient use efficiency resulting from the combined application of Nano NPK and compost are primarily attributable to the synergistic interaction between both inputs. Specifically, Nano NPK supplied a prompt and adequate nutrient source to fulfill crop requirements, while compost improved moisture

retention and provided essential elements supporting plant growth. Consequently, integrating Nano NPK with compost is established as an effective management strategy for semi-arid regions to optimize the physiological performance and nutrient use efficiency of faba bean.

Keywords: Nano-fertilizer, Organic amendment, Nutrient use efficiency, Physiological traits, Semi-arid agriculture, Sustainable fertilization.

الملخص

يُمثّل تحسين كفاءة استخدام العناصر الغذائية من خلال الإدارة المتكاملة للتسميد نهجاً واعداً لتعزيز إنتاج الفول البلدي في النظم الزراعية البيئية شبه الجافة. وعليه، أُجريت تجربة حقلية في منطقة وادي عتبة جنوب ليبيا خلال موسم النمو 2026/2025 لتقييم فعالية سماد النانو نيوتروجين والفوسفور والبوتاسيوم (NPK) والكمبوست، سواء استُخدما منفردين أو مجتمعين، على الأداء الفسيولوجي وكفاءة استخدام العناصر الغذائية لصنفين من الفول البلدي (Vicia faba L.). صُممت التجربة وفق تصميم القطاعات الكاملة العشوائية (RCBD) بسبع معاملات تسميد وثلاث مكررات. قُررت محتوى أوراق الماء، وقيم الكلوروفيل (SPAD)، ومعدل النمو النسبي (RGR)، بالإضافة إلى كفاءات استخدام النيتروجين (N)، والفوسفور (P)، والبوتاسيوم (K). أظهرت النتائج أن لمعاملات التسميد، والأصناف، وتفاعلاتها تأثيرات معنوية عالية على جميع الصفات المدروسة (P < 0.001). وفيما يتعلق بمعاملات التسميد، تبين أن التطبيق المشترك لسماد النانو NPK والكمبوست (T7) هو الأفضل، حيث أعطى أعلى محتوى مائي للأوراق، وقيم SPAD، ومعدل نمو نسبي، وكفاءة استخدام عناصر غذائية، تلاه التطبيق المشترك لـ 50% نانو NPK مع 50% NPK معدني (T5) ثم توليفة NPK المعدني مع الكمبوست (T6)، بينما سجلت معاملة الشاهد (T1) أدنى أداء. ومقارنة بالشاهد، سجلت المعاملة (T7) زيادات في محتوى أوراق الماء، وقيم SPAD، ومعدل النمو النسبي، وكفاءة استخدام النيتروجين، والفوسفور، والبوتاسيوم بنسبة 28%، و26%، و31%، و31%، و29%، و31% على التوالي. علاوة على ذلك، تفوق الصنف المستورد على الصنف المحلي في جميع المتغيرات المقاسة. يمكن إرجاع التحسن في الأداء الفسيولوجي وكفاءة استخدام العناصر الغذائية الناتج عن التطبيق المشترك لسماد النانو NPK والكمبوست إلى التأثير التآزري لكلا المسمدين؛ إذ وفر سماد النانو NPK مصدراً كافياً وسريعاً للعناصر الغذائية لتلبية احتياجات المحصول، بينما حسّن الكمبوست الاحتفاظ بالعناصر ورفد النبات بالعناصر الأساسية لنمو أفضل. وبناءً على ذلك، يُستنتج أن استخدام سماد النانو NPK مع الكمبوست يُعد استراتيجية ملائمة للمناطق شبه الجافة لتعزيز الأداء الفسيولوجي وكفاءة استخدام العناصر الغذائية للفول البلدي.

الكلمات المفتاحية: الأسمدة النانوية، المُحسّنات العضوية، كفاءة استخدام العناصر الغذائية، الصفات الفسيولوجية، الزراعة شبه الجافة، التسميد المستدام..

Introduction

Faba bean (*Vicia faba* L.) is one of the most significant grain legumes of the world, and a significant source of plant protein for human and animal nutrition. It is rich in protein, carbohydrate, dietary fiber, vitamins and essential minerals. In addition to its nutritive properties, faba bean is known to have a symbiotic biological nitrogen fixation that results in soil fertility enhancement without the need for synthetic nitrogen fertilizers, contributing to the sustainability of cropping systems. Hence, nutrient use efficiency is a key research challenge for sustainable agriculture for improving faba bean productivity and quality (Brandt *et al*., 2026; Dhull *et al*., 2022).

Nanotechnology has become a significant step in the present-day agri-technology to deliver nutrients in a controlled and targeted manner using Nano-fertilizers. Nano-fertilizers possess the unique advantage of small size of the particles and their high specific surface area which ensure controlled release of nutrients and make them more available, more uptaken and more translocated to different parts of the plant, increasing the nutrient use efficiency, plant growth and productivity of the plants, while reducing the losses of the nutrients and the negative effects of excess use of conventional mineral fertilizers. The merits of using Nano-fertilizers in sustainable agriculture production in various environmental conditions are a promising option (Couto Junior *et al*., 2025; Anagaw *et al*., 2024; Usman *et al*., 2020).

Ahmad *et al*. (2026) demonstrated that the application of Nano NPK -fertilizers and chitosan markedly improved leaf water status, photosynthetic capacity, plant growth, and nutrient use efficiency, the combined application of Nano NPK-fertilizers improved nutrient use efficiency, promoted vegetative growth, and increased biomass production in faba bean (Elmahdi *et al*., 2026), Nano-NPK foliar application significantly improved plant height, number of leaves, pod number, nutrient uptake, and seed yield (Shartoh *et al*. (2026).

Helal *et al*. (2026) found that the use of nano-formulated phosphorus and potassium fertilizers significantly enhanced the level of chlorophyll, photosynthesis, uptake of nutrients, antioxidant activity, and biomass production of faba bean under salinity conditions, with better results than conventional fertilizers on plant growth and salinity tolerance (Aziz and Zrar 2021), the application of Nano NPK via foliar significantly enhanced the plant height, leaf number, chlorophyll content, pod number, seed weight and total seed yield of broad bean and improved crop productivity without causing any negative impact on the genomic stability of beans as measured by (Salama *et al*. 2022).

Tadesse *et al*. (2025) indicated that there were significant improvements in the growth, biomass production, nutrient availability and soil fertility of faba bean with organic amendments and bio-inoculants in acidic soil. The use of organic amendments (particularly vermicompost) had a significant effect on soil microbial biomass, rhizobium activity, pod yield and productivity of faba bean (Mosavi-Azandehi *et al*. 2023). There was a significant improvement in grain yield, biomass, nodulation, nutrient uptake (N, P and S) and residual soil N under traditional compost, vermicompost and EM-compost as compared to mineral fertilizer alone. EM-compost produced the highest economic return as mentioned by Bezabeh *et al*.(2021) .

Gomaa and Afifi (2021) reported that Compost significantly enhanced nodulation, nutrient uptake, rhizosphere biological activity, growth, and seed yield of faba bean, especially when integrated with mineral NPK, Bio-organic fertilization using compost and *Rhizobium* significantly improved plant growth, yield, nutrient uptake, and soil biological activity compared with mineral fertilization alone (Foda *et al*. 2021). Organic materials significantly improved soil fertility, nutrient retention, nutrient availability, and the growth of faba bean, particularly in calcareous soils. Humic and fulvic acids extracted from organic materials further enhanced plant performance according to (Farid *et al*. 2021).

Therefore, the primary research aim is to investigate the effects of Nano NPK -fertilizers in combination with compost and conventional mineral fertilizers on growth and physiological indicators in two faba bean varieties to determine which fertilization strategy is most productive, nutrient use efficient and sustainable for faba bean production.

Material and methods

Experimental Site

In the environment of Wadi Etbah, Southern Libya, which is semi-arid during the 2025/2026 growing season, mineral NPK (comprising nitrogen (N), phosphorus (P) and potassium (K) fertilizers) application, Nano NPK fertilizer application and compost application were tested in relation to their effects on the physiological performance and nutrient use efficiency of two cultivars of faba bean (*Vicia faba* L.). The experimental site has a hot arid climate with low annual rainfall and high temperatures occurring for most of the growing season.

Soil sampling and analysis.

Soil physical and chemical properties of the experimental field were assessed from the initial soil sample collected in the experimental field before land preparation leveling, a composite soil sample was taken from the soil at 0-20 cm depth. Soil samples were taken again post harvest to assess the impact of the fertigation treatments on soil fertility. All soil samples were air dried and crushed, sieved through 2 mm and then analyzed for soil and plant in the Soil and Plant Analysis Laboratory, Research Center, Sebha University, Libya.

Table 1. Soil properties before sowing the soil in the experimental plot

Chemical properties	
pH	8.2
EC (dS m^{-1})	1.7
Organic matter (%)	0.50
$CaCO_3$ (%)	23.5
HCO_3^- (%)	11.5
Available N (mg kg^{-1})	26.0
Available P (mg kg^{-1})	6.8
Available K (mg kg^{-1})	10.0
Fe (mg kg^{-1})	4.5
B (mg kg^{-1})	0.9
Cu (mg kg^{-1})	2.0
Zn (mg kg^{-1})	1.0
Mn (mg kg^{-1})	5.0
Physical properties	
Sand (%)	61.1
Silt (%)	18.2
Clay (%)	20.2
Texture class	Sandy clay loam

Plant Materials and Land Preparation

Two cultivars of faba bean (*Vicia faba* L.) were used: locally cultivated type which is cultivated locally in southern Libya and imported (Spanish) cultivar from the agricultural market.

Before sowing the experimental field was ploughed and cleaned from the residues of the previous barley crop. The land was flattened, and then divided as per the experimental design into the experimental plots.

The experimental plots were each 3.75 m², with five rows of 1.5 m each row with a spacing of 0.50 m. The seeds were planted in hills with 25 cm of spacing. The planting rate was 3 seeds per hill which were thinned to 2 plants at establishment.

Experimental Design

The experiment was conducted in a Randomized Complete Block Design (RCBD) and carried out in a 7 x 2 factorial treatment design with three replications. The first was the seven fertilization treatments and second the two cultivars of faba bean.

The treatments were Control (T1), Mineral NPK fertilizer (recommended dose) (T2), Nano NPK fertilizer (recommended dose)(T3), Compost (T4), 50% Mineral NPK + 50% Nano NPK (T5), Mineral NPK + Compost (T6) , Nano NPK + Compost (T7).

Fertilization Treatments

A mineral fertilization strategy of diammonium phosphate (DAP, 18% N and 46% P_2O_5), urea (46% N) and potassium sulfate (50% K_2O) was recommended, with application amounts of 150, 87 and 120 kg ha^{-1}, respectively.
The soil was treated by adding diammonium phosphate during tillage. Two equal doses of urea and potassium sulphate were applied; the first about 2–3 weeks after the seedlings emerged and the second at the start of flowering to encourage development of pods and filling of seeds. Potassium was applied as potassium sulphate, the recommended source of potassium for growing faba bean in the study area.

Use of Nano NPK fertilizer and compost.

The nano fertilizer was a commercial Nano NPK (19:19:19) enriched with micronutrients (Fe, Mg, Mn, Zn, B, and Cu), amino acids (5%) and algal extracts(%0.5) .
Nano NPK was sprayed at 25, 40 and 55 days after sowing at 2 g L^{-1} as foliar spray.
The compost was applied to the soil at 3.75 kg per experimental plot (10 t ha-1) and was thoroughly mixed with the topsoil when land preparation was done.

Measured Traits

The following physiological and nutrient-use efficiency parameters were measured at the proper growth stages:

- Leaf water content (%) was determined using the fresh and dry weight method with this formula:

$$\boldsymbol{Leaf\ Water\ Content\ (LWC, \%) = [(FW - DW) / FW] \times 100}$$

FW = Fresh weight of the leaf (g).
DW = Dry weight of the leaf after oven drying to constant weight (g).

Chlorophyll content (SPAD value) was measured using a portable SPAD chlorophyll meter.

- Relative Growth Rate is determined based on two time points of measurements. The equation is :
  $RGR = (ln(S2) - ln(S1)) / (t2 - t1)$, where ln is the natural logarithm, t1 and t2 are the times of the first and second measurements, and S1 and S2 are the sizes at times t1 and t2. (Hoffmann *et al*., 2002)
- Nitrogen use efficiency (NUE):
  The Difference Method. $PFR = (NF - NC)/R$, where NF is total N uptake in fertilized plots, NC is total N uptake in unfertilized plots, and R is the fertilizer N application rate. EU Nitrogen Expert Panel. (2016).
- Phosphorus Use Efficiency (PUE):
  Procedure: Recovery by crops of fertilizer P applied can be computed using the different method that is considered as the traditional one. University of Adelaide. (n.d.). The productivity of phosphorus fertilizer in soils.
- Potassium Use Efficiency (KUE):
  Procedure Agronomic K use efficiency (KUE) is the yield of a crop divided by unit K made available. (Murrell *et al*., 2021)

Statistical Analysis

Analysis of variance (ANOVA) appropriate to the factorial experiment, Randomized Complete Block Design (RCBD) was used to analyse all the experimental data, using the statistical software CoStat. The Least Significant Difference (LSD) test at 5% probability level ($P \leq 0.05$) was used to separate the treatment means.

Results

The leaf water content was significantly influenced by the fertilization treatments and cultivar ($P < 0.001$) (Figure 1 A). The highest Leaf Water Content was achieved for the treatment of Nano NPK + Compost (T7) with 87.9% in local cultivar and 91.9% in imported cultivar. This was followed by 50% Nano NPK + 50% Mineral NPK (T5) treatment that recorded 84.2% and 88.6% respectively. The lowest values were found in the control treatment (T1) with 68.1% for local cultivar and 72.1% for imported cultivar .

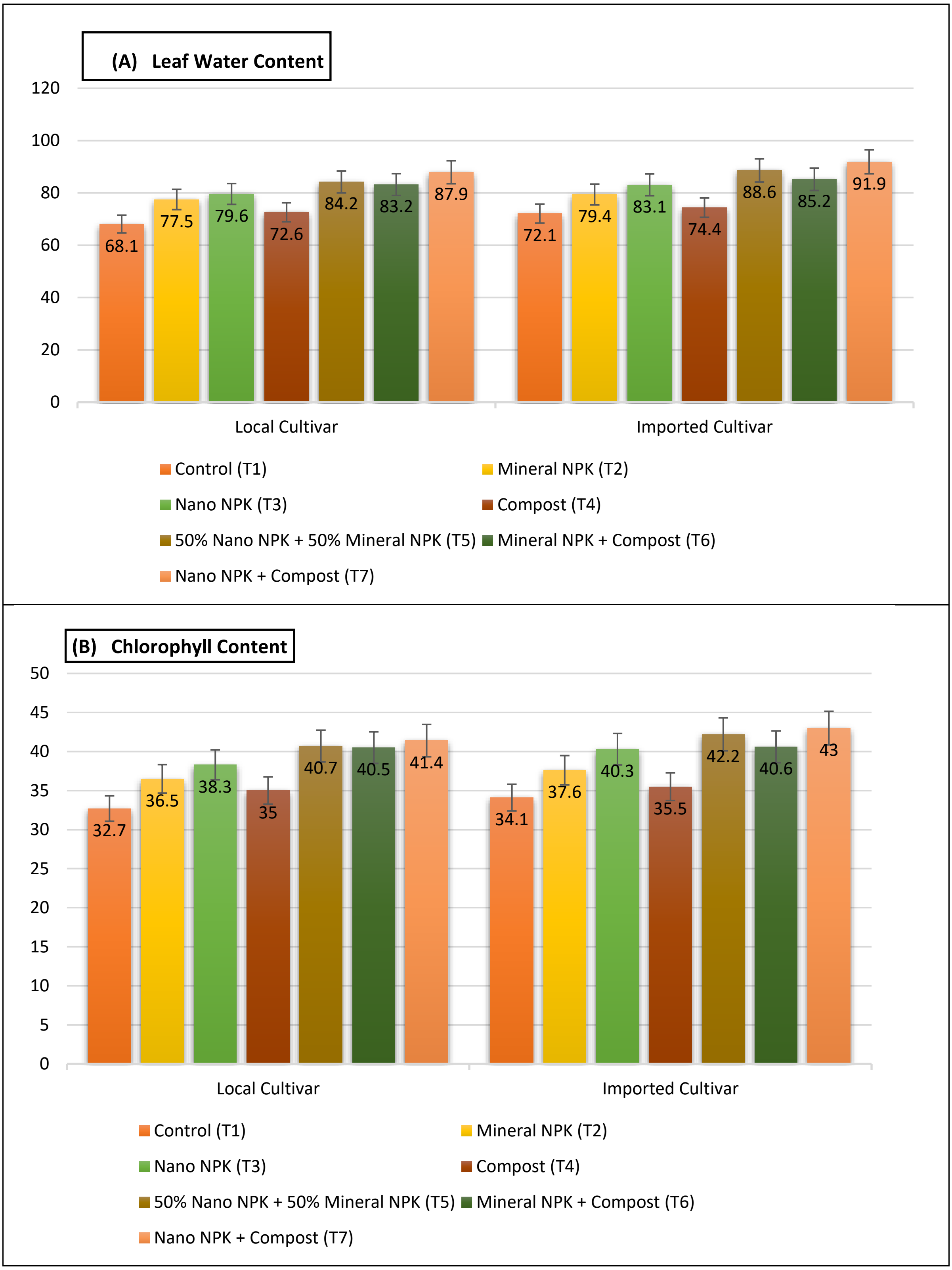
Fertilization treatments and cultivar ($P < 0.001$) significantly affected chlorophyll content. The highest SPAD were obtained by treatment with Nano NPK + compost (T7) with SPAD value of 41.4 and 43.0 for local and imported cultivars, respectively. The second highest chlorophyll was observed in plants with 50% Nano NPK + 50% Mineral NPK (T5) which were 40.7 and 42.2, respectively. In contrast, the control treatment had the lowest chlorophyll level (32.7 and 34.1, respectively) (Figure 1B).

The fertilization treatments and cultivars had significant effects on relative growth rate ($P < 0.001$). Nano NPK + Compost (T7) showed the highest RGR of 0.0178 g g^{-1} day^{-1} and 0.0196 g g^{-1} day^{-1} for local and imported cultivar respectively. The 50% Nano NPK + 50% Mineral NPK (T5) treatment ranked second, with values of 0.0176 and 0.0187 g g^{-1} day^{-1}, respectively. The RGR of the untreated control plants (g g^{-1} day^{-1}, 0.0137 and 0.0149) were the lowest (Figure 1 C).

The fertilization treatments had a significant effect on N use efficiency ($P < 0.001$). The highest NUE values were found in Nano NPK + Compost (T7); 50.4 mg kg-1 for local cultivar and 54.3 mg kg-1 for imported cultivar. The 50% Nano NPK + 50% Mineral NPK (T5) treatment recorded the second-highest NUE values of 50.3 and 51.7 mg kg-1 respectively. The NUE values were lowest in the control treatment (39.4 and 40.6 mg kg^{-1}, respectively) (Figure 2 D).

The use efficiency of phosphorus (UEP) varied greatly between the fertilization treatments and cultivars ($P < 0.001$). Nano NPK + Compost (T7) gave the highest values of PUE at 28.5 mg kg-1 and 29.6 mg kg-1 for local and imported cultivar respectively. The second best treatment was 50% Nano NPK+50% Mineral NPK (T5) with the values 27.5 and 28.7 mg kg-1 respectively. The values of PUE were lowest in the control treatment (22.1 and 22.6 mg kg-1, respectively) (Figure 2 E).

The fertilization treatments and cultivar ($P < 0.001$) significantly affected potassium use efficiency. The most optimum treatment for this experiment was the Nano NPK + Compost (T7) which produced the highest KUE values of 37.8 mg kg^{-1} and 40.3 mg kg^{-1} in local and imported cultivars, respectively. The 50% Nano NPK + 50% Mineral NPK (T5) treatment was the 2nd treatment with 37.4 and 38.7 mg kg^{-1} respectively. The values of KUE were the lowest in the case of the control treatment (28.9 and 30.9 mg kg-1 respectively) (Figure 2 F). The overall result indicated that the imported cultivar exhibited higher potassium use efficiency under all treatments, thus proving its higher ability to use available potassium under better fertilization regime.


(A) Leaf Water Content
120
100
80
60
40
20
0
68.1
77.5
79.6
72.6
84.2
83.2
87.9
72.1
79.4
83.1
74.4
88.6
85.2
91.9
Local Cultivar
Imported Cultivar
Control (T1)
Mineral NPK (T2)
Nano NPK (T3)
Compost (T4)
50% Nano NPK + 50% Mineral NPK (T5)
Mineral NPK + Compost (T6)
Nano NPK + Compost (T7)
(B) Chlorophyll Content
50
45
40
35
30
25
20
15
10
5
0
32.7
36.5
38.3
35
40.7
40.5
41.4
34.1
37.6
40.3
35.5
42.2
40.6
43
Local Cultivar
Imported Cultivar
Control (T1)
Mineral NPK (T2)
Nano NPK (T3)
Compost (T4)
50% Nano NPK + 50% Mineral NPK (T5)
Mineral NPK + Compost (T6)
Nano NPK + Compost (T7)

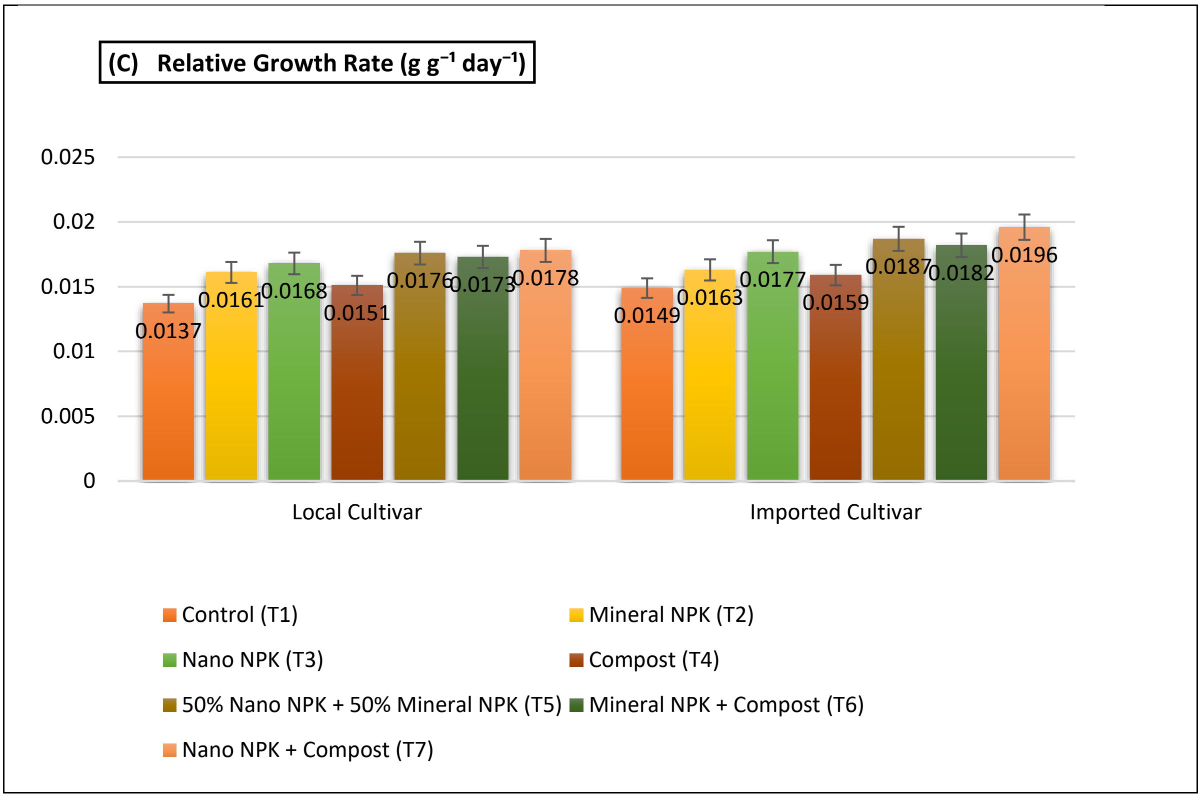
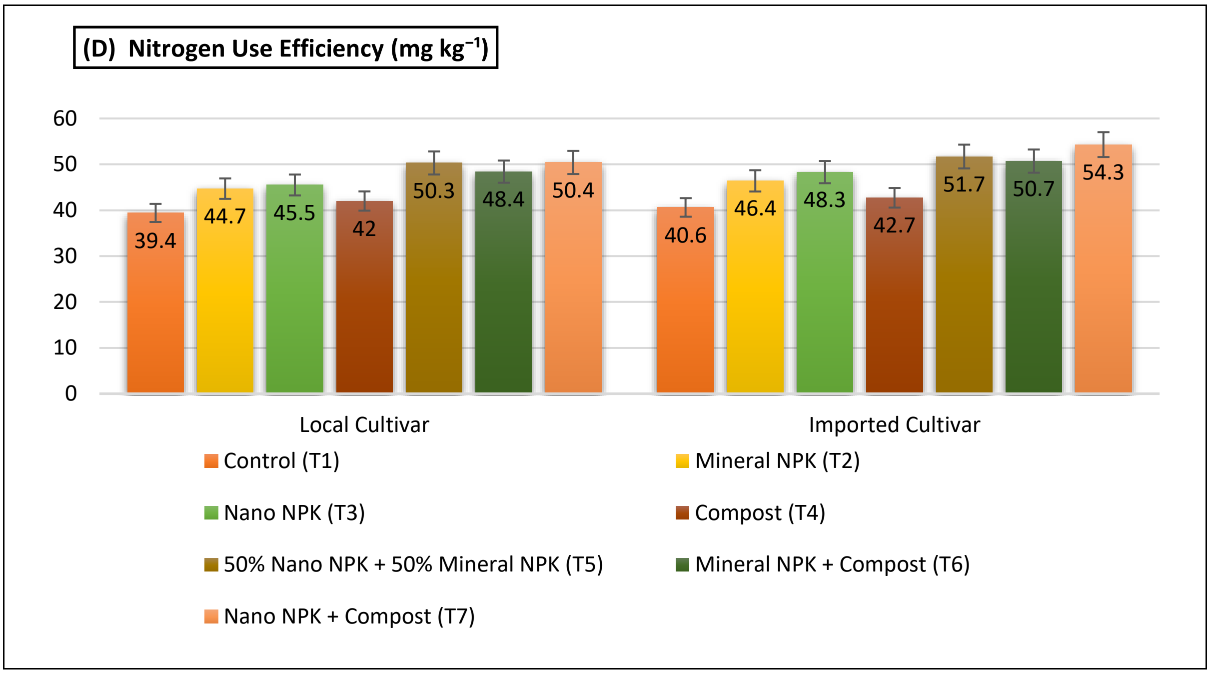


Figure 1. Effects of nano NPK and compost fertilization on nutrient use efficiency of two faba bean (*Vicia faba* L.) cultivars: (A) Leaf Water Content, (B) Chlorophyll Content and (C) Relative Growth Rate (g g^{-1} day^{-1}).



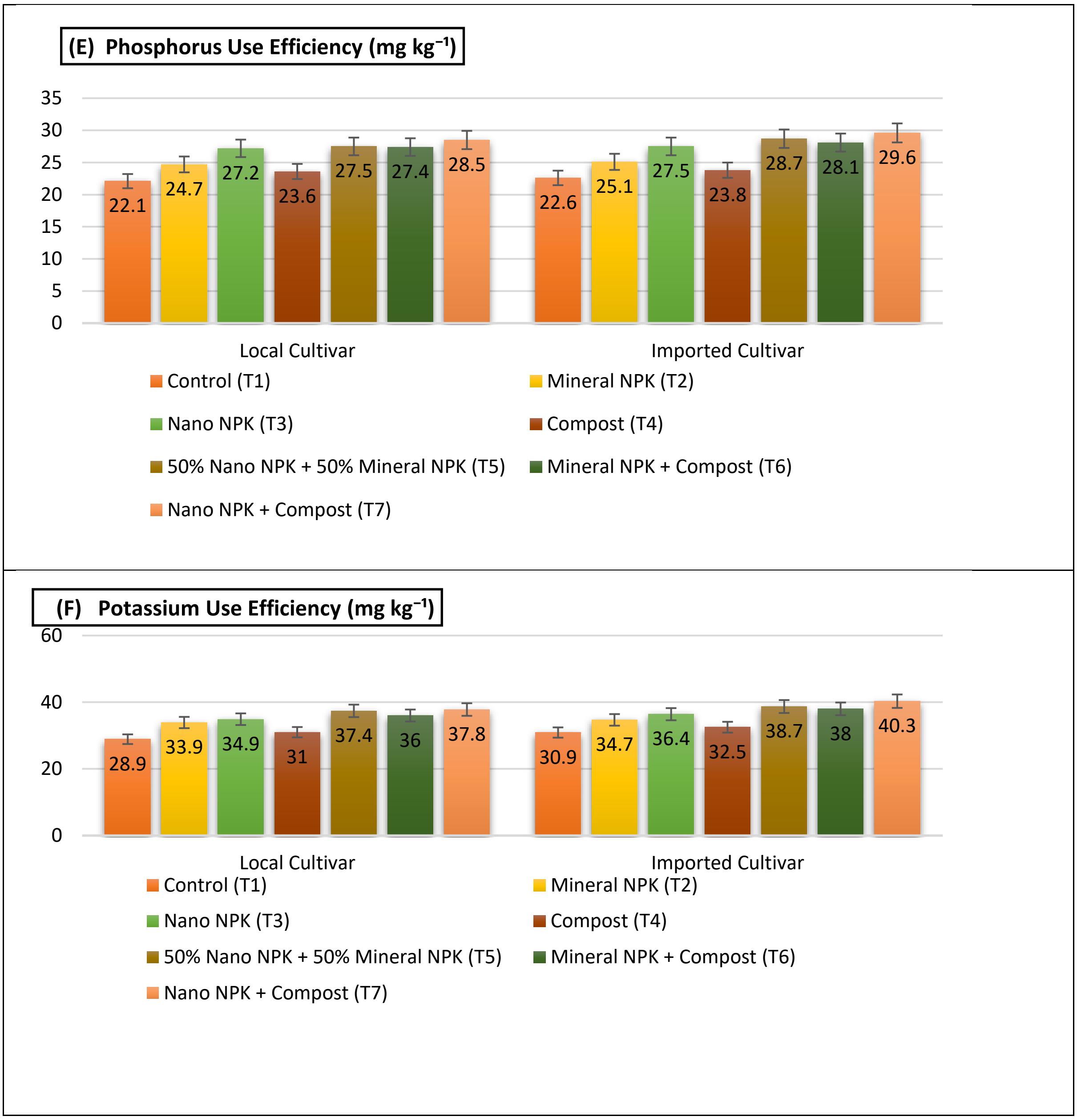


Figure 2. Effects of nano NPK and compost fertilization on nutrient use efficiency of two faba bean (*Vicia faba* L.) cultivars: (D) nitrogen use efficiency (NUE), (E) phosphorus use efficiency (PUE) and (F) potassium use efficiency (KUE).

Discussion

Effect of Nano NPK and Compost on Leaf Water Content(%) .

The improved leaf water content noticed after the combined application of Nano NPK and compost may be due to the amending effect of both amendments to plant water relations as well as to soil water availability. Nano NPK fertilizers can be used to improve the uptake of water in plants by promoting osmotic adjustment, maintaining turgidity in cells, increasing the stability of the membrane and facilitating better absorption of nutrients, so that the plants can keep their tissue hydrated. Compost on the other hand, has a positive effect on soil physical properties such as aggregation, porosity, water holding capacity, root growth and water uptake. The combination of these two fertilization methods therefore resulted in better water acquisition and retention compared to either amendment alone, and thus the best leaf water content was obtained with Nano NPK + Compost.

The current results confirm the previous results that showed nano-fertilizer to have a positive effect on plant water relation by increasing the nutrient uptake, osmotic regulation, and enhancing the physiological performance of the plants (Salama *et al*., 2022; Khalifa *et al*., 2024; Omer *et al*., 2025). Similarly, there are numerous reports that compost amendments enhance water status of plants, including improving soil moisture retention and root zone environment, thus increasing soil water availability for crop growth (Oyetunji *et al*., 2022; Bezabeh *et al*., 2021). Moreover, Amer *et al*. (2023) reported that the simultaneous application of nano-fertilizer and compost had greater beneficial effects on water productivity and water status of plants in salinity stress conditions than using each nano-fertilizer or compost alone, which confirms the beneficial effect of the combination of nano-fertilizer with organic amendments.

Effect of Nano NPK and Compost on Chlorophyll Content (SPAD)

This significant improvement in chlorophyll content after the application of Nano NPK coupled with compost indicates the synergistic effect of both the fertilizers on the nutrient availability and photosynthetic ability. Nano NPK fertilizers deliver controlled release microelements and macro elements that are easily absorbed by the plant and stimulate the formation of chlorophyll, chloroplasts and photosynthesis efficiency. Compost also enhances soil fertility by releasing nitrogen and other micronutrients required for chlorophyll synthesis, and by promoting microbial activity that boosts the mineralization of nutrients and cycling. Therefore, the combined use of Nano NPK and compost provided a steady and balanced nutrition and it has been observed to be more effective in accumulation of chlorophyll than individual application of either. The increase in the chlorophyll content that was measured in the present study was also consistent with the better leaf water status measured, indicating better hydration of the plants further promoted photosynthetic activity and chlorophyll stability.

The results are consistent with earlier reports indicating that nano-fertilizers have the potential to greatly boost chlorophyll content and photosynthetic efficiency in various crops by increasing the uptake and utilization of nutrients (Salama *et al*., 2022; Baral Dola *et al*., 2022; Khalifa *et al*., 2024; Omer *et al*., 2025). Similarly, the positive effects of compost on chlorophyll levels have been attributed to its enhancement of soil fertility, nutrient availability and microbial activity, which positively influence continued photosynthesis and plant growth (Bezabeh *et al*., 2021; Oyetunji *et al*., 2022). In conclusion, these studies have confirmed the present results for the integration of Nano NPK with compost which showed that it was a more efficient approach for improving the photosynthetic performance and increasing the chlorophyll synthesis in faba bean than the use of either amendment alone.

Effect of Nano NPK and Compost on Relative Growth Rate (g g −1 day −1)

The enhanced relative growth rate recorded after the combined application of Nano NPK and compost could be explained by the improved leaf water content, photosynthesis rate, and nutrient availability. The higher leaf water content and chlorophyll content obtained from the current experiment suggest that the plants had higher photosynthetic activity and assimilation of carbon. Nano NPK fertilizers promoted the absorption of nutrients due to their slow-release mechanism and high use efficiency. Meanwhile, the compost improved the fertility of the soil, thus facilitating the availability of nutrients and water to the plants. As a result, the combined application of compost and Nano NPK created a conducive environment for the continuous growth of the plants, therefore, leading to a higher relative growth rate than when either of the two amendments was used alone.

The current findings agree with the results of previous studies that evaluated the impact of nano-fertilizers on plant growth and development. For instance, Salama *et al*. (2022) and Baral Dola *et al*. (2022) established that nano-fertilizers improved the biomass production of crops by enhancing the nutrient uptake, photosynthetic efficiency, and biomass productivity of the plants. Salama *et al*. (2022) found that the application of nano-fertilizers on faba bean increased the biomass production of the crop, while Baral Dola *et al*. (2022) proved that nano-fertilizers could improve the growth rate and vegetative development of legumes. On the other hand, various studies have shown that the application of compost also improves crop production by enhancing the fertility of the soil and promoting the availability of nutrients and water to the plants (Bezabeh *et al*., 2021; Oyetunji *et al*., 2022). The current results are consistent with the previous findings that show that the combined application of compost and Nano NPK can create a suitable environment for better plant growth than when either of the two soil amendments is used alone.

Effect of Nano NPK and Compost on Nitrogen Use Efficiency (NUE)

The enhanced nitrogen use efficiency observed in response to the combined application of Nano NPK and compost may be attributed to the synergistic effects of these two treatments which improved nitrogen availability, uptake, and utilization by the faba bean plants. The gradual release of nutrients from Nano NPK fertilizers increased nitrogen availability to the crop and minimized nitrogen losses via leaching and volatilization, thus improving nitrogen uptake and utilization. The application of compost also enhanced nitrogen availability by improving nitrogen mineralization and retention. The combined application of compost with Nano NPK fertilizers probably increased nitrogen uptake and utilization which explains the observed high values of chlorophyll content, vegetative growth, and relative growth rate in the current experiment.

The results of the current study are in agreement with the findings of previous studies that reported that the application of nano-fertilizers improved nitrogen uptake and nitrogen use efficiency by increasing nitrogen availability and fertilizer use efficiency (Salama *et al*., 2022; Khalifa *et al*., 2024; Omer *et al*., 2025). Similarly, a number of previous studies have also shown that compost application increased nitrogen availability by improving nitrogen mineralization and retention, and nitrogen use efficiency by reducing nitrogen losses through leaching and volatilization (Bezabeh *et al*., 2021; Oyetunji *et al*., 2022). The current findings are consistent with those previously reported which demonstrates that the combined application of Nano NPK and compost can improve nitrogen use efficiency by faba bean.

Effect of Nano NPK and Compost on Phosphorus Use Efficiency (PUE)

The improved nitrogen use efficiency observed in the treatment with Nano NPK and compost could be attributed to the fact that both amendments contributed to increased nitrogen availability, uptake, and utilization by faba bean plants. The use of Nano NPK fertilizers with controlled release of nutrients increased nitrogen availability to plants throughout the growing season while reducing losses due to leaching and volatilization, thus improving nitrogen uptake and utilization efficiency. The application of compost also increased nitrogen availability due to improved nitrogen mineralization and retention in the soil, as well as enhanced nitrogen nutrition of plants. Consequently, the combined application of Nano NPK and compost resulted in improved nitrogen nutrition of faba bean plants which might explain the increased chlorophyll content, improved vegetative growth, and higher relative growth rate observed in this study.

The results of this study are in agreement with previous findings which reported that nano-fertilizers could increase nitrogen uptake and nitrogen use efficiency by improving nitrogen availability and fertilizer use efficiency (Salama *et al*., 2022; Khalifa *et al*., 2024; Omer *et al*., 2025). Similarly, previous studies also showed that compost application could improve nitrogen availability by enhancing nitrogen mineralization, increasing nitrogen retention in the soil, and improving nitrogen utilization by plants (Bezabeh *et al*., 2021; Oyetunji *et al*., 2022). The consistency of results with previous findings confirms that the combined application of Nano NPK and compost could be an effective strategy for improving nitrogen use efficiency while also promoting nitrogen nutrition of faba bean plants.

Effect of Nano NPK and Compost on Potassium Use Efficiency (KUE)

The increased P-use efficiency under the combined application of Nano NPK and compost could be explained by the positive effect of both treatments on phosphorus availability and utilization. The application of Nano NPK fertilizers, when combined with compost, improved P-availability in the calcareous soil through their controlled-release nature and reduced P-fixation by calcium. In addition, the incorporation of compost into the soil improved P-availability by liberating organic acids during decomposition and promoting the proliferation of P-solubilizing microorganisms that utilize phosphorus. Hence, the combination of Nano NPK with compost resulted in a higher P-use efficiency than the individual application of either treatment.

The results of the current study are in agreement with the findings of previous studies that nano-fertilizers could increase P-use efficiency by improving P-availability and fertilizer utilization efficiency (Salama *et al*., 2022; Omer *et al*., 2025). Similarly, compost has been reported to increase P-availability in the soil by decreasing P-fixation, enhancing microbial activity, and promoting P-solubilization (Chtouki *et al*., 2022; Oyetunji *et al*., 2022). In general, previous findings support the current results and confirm that the combined application of Nano NPK and compost can be a promising strategy for improving P-nutrition and P-use efficiency in calcareous soils.

Conclusion

Among all fertilization treatments the combined application of Nano NPK and compost proved to be the most effective fertilization strategy, leading to improved physiological performance and fertilizer use efficiency of both faba bean cultivars than mineral NPK, compost and these two fertilization methods alone. Mineral NPK was also partially replaced by Nano NPK, which increased the plant performance, showing higher efficiency in the utilization of nutrients and less dependency on conventional fertilizers. The cultivar imported was consistently superior to the local cultivar, emphasizing the need for cultivar selection for optimum use of integrated nutrient management. In general, the use of Nano NPK in combination with compost is a sustainable and efficient method to enhance productivity of faba bean under the semi-arid conditions found in southern Libya.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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