EFFECT OF SOIL AND FOLIAR PHOSPHATE FERTILIZATION ON BROAD BEAN YIELD IN A MEDITERRANEAN AGROECOSYSTEM

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Abstract. Broad beans (*Vicia faba*) are essential legumes for human and animal nutrition, but their productivity is often hampered by inadequate agronomic practices, particularly fertilizer choice and application methods. This study compared three methods of applying phosphate fertilizers to broad beans grown in the Mitidja plain in Algeria: (1) background fertilization with triple superphosphate (TSP 46%), (2) foliar fertilization with an Agriphos-type fertilizer and (3) a combined approach integrating both methods. Biometric measurements carried out at flowering and pod maturity stages showed that the combined approach offered the best theoretical fresh grain yield, with lower seed phosphorus content, while foliar fertilization significantly increased seed phosphorus concentrations. These results provide essential data for optimizing bean cultivation, but further multi-season studies are needed to validate these practices and establish recommendations applicable to real world conditions.
Keywords: *Vicia faba, phosphorus content, biometric measurements, flowering stage, pod maturity, crop optimization, Algeria*

Introduction

Agriculture plays a pivotal role in reducing poverty, enhancing livelihoods, and promoting economic growth, while ensuring food security and self-sufficiency (Imen and Reguia, 2023). In Algeria, the agricultural sector has long been a fundamental pillar, providing both food and employment and sustaining rural areas (Adair et al., 2022). By 2016, agriculture ranked third after the services and hydrocarbons sectors, contributing 12.3% to the nation's Gross Domestic Product (GDP), an increase of 1.2% compared to 1999 (MADR, 2024). As of 2018, Algeria's population stood at 42.4 million, half of whom where under the age of 25. Projections from the National Statistical Office (ONS) estimate that the population will reach 51 million by 2030 and exceed 70 million by 2050, further amplifying Algeria's reliance on external resources to ensure food supply (Bouchafaa, 2023). To address Algeria's growing food vulnerability, it is imperative to improve agricultural productivity (Pawlak and

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Kołodziejczak, 2020). Such improvements are essential not only for tackling natural challenges, but also for enhancing food security in the face of climate variability and resource limitations (Bessaoud et al., 2019).

Similar to many regions globally, Algeria is increasingly affected by climate change, particularly in its central and southern areas, where drought has become a persistent issue (Bougrine et al., 2022). The complexity and interconnectivity of climate-related impacts make it challenging to devise simple adaptive strategies to enhance agricultural resilience (Beillouin et al., 2020). The Mitidja Plain, a narrow coastal plain 100 km long and located in the center of northern Algeria, benefits from a Mediterranean climate conducive to agricultural activity (Imache et al., 2006). This also highlights the significant potential for economic growth and historical agricultural prosperity (Bellout et al., 2020). In addition, it has a favorable geomorphological structure, with vast fertile lands and gentle slopes, allowing the emergence of an endogenous agricultural sector composed of cereals, vegetables, fruit trees, and other crops, including beans (Khouli and Djabri, 2011; Bouderbala, 2018). Thus, the cultivation of leguminous crops plays a vital role because of their significant contribution to plant-based protein production. These crops are also well-suited for enhancing bio-productivity and reclaiming marginal soils (Bougrine, 2023).

Vicia faba (commonly known as faba bean, broad bean, horse bean, or Windsor bean) was one of the earliest plants to have been domesticated during the Neolithic period (Cubero, 1974; Belhadi et al., 2018). It is primarily used for animal feed and human consumption in the form of fresh or dried seeds (Duc et al., 2010). Often referred to as ‘poor man’s meat’ due to its high protein content (Van de Wouw et al., 2001), the broad bean is also employed as a bio-organic fertilizer in arid regions (Chafi and Bensoltane, 2009), thereby contributing to sustainable agriculture through soil fertility management. It plays an essential role in crop rotation because of the large amount of nitrogen it fixes, ranging from 60 to 250 kg/ha/year and up to 600 kg/ha/year (Torres et al., 2012). In particular, the annual average production of *Vicia faba* in Algeria reached 44,353 tons in 2022, harvested from a sown area of 32,709 ha, with an average yield of about 1.23 tons per hectare (FAOSTAT, 2024). The cultivation of broad beans in Algeria is characterized by low yields, mainly due to agro-technical issues, such as sowing dates and doses, as well as the dose and type of fertilizer (Hadou el Hadj et al., 2022). The amount of nutrients taken up by the plant and the rate of uptake depend on several factors, such as plant variety, sowing date, crop rotation, and soil and climatic conditions (FAO, 2003). Thus, the method and type of fertilizer used are crucial elements of good agricultural practices (Lichman et al., 2018).

Phosphorus is a major nutrient, particularly essential for legumes. It is required in large quantities in young cells, such as shoots and root tips, where metabolism is high and cell division is rapid (Kumar et al., 2019). It also contributes to flower initiation, and seed and fruit development (Ndakidemi and Dakora, 2007). Legumes, such as the broad bean, require phosphorus for their growth and seed development, especially for nitrogen fixation, an energetically costly process (Nkaa et al., 2014). Broad beans may require phosphorus inputs in the range of 20 to 30 kg P ha-1 (FAO, 2000). Many authors have reported a significant increase in the growth, yield components, and yield of broad beans with an increased rate of mineral phosphorus application (Najm, 2010; Mousa and El-Sayed, 2016; El-Sayed et al., 2017). Phosphorus also increases plant resistance to drought (Azzam, 2019). In this context, new methods such as foliar and soil fertilization have been introduced to stimulate nutrient uptake by plants (Niu et al., 2021). However, their effectiveness in optimizing bean cultivation in the Mitidja Plain warrants a thorough study.

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This study aimed to assess the impact of soil and foliar phosphate fertilization on bean yield in the Mitidja Plain. To this end, our research proposes to study the behavior of bean crops (*Vicia faba* major) with phosphorus fertilization by adopting three different modes of phosphorus fertilizer application: soil fertilization (ground fertilizer) in the form of triple superphosphate (TSP 46%), foliar fertilization with a foliar fertilizer (Agriphos), and a combined treatment between the two previous fertilization modes. We will evaluate which fertilization method most effectively improves productivity, taking into account environmental conditions and local farming practices. This research could have wider implications for similar agricultural regions and will enrich the scientific literature on crop nutrition, particularly for legumes, which are essential for sustainable agriculture because of their ability to fix nitrogen.

Material and methods

Study area characteristics and environmental conditions

The experiment was conducted at the Experimental Station of the National School of Agricultural Sciences (ENSA), situated on the Hassen BADI plateau in the municipality of Oued Semmar, daïra of El-Harrach, and the wilaya of Algiers. The ENSA Experimental Station is geographically located north of the Mediterranean Sea and is surrounded by five houses and dunes. To the east, it is bordered by the localities of El-Alia and Bab-Ezzouar and to the west by the city of El-Harrach. To the south, it borders the municipality of the Oued Semmar. The El-Harrach region lies at a longitude of 38° and a northern latitude of 36°43, with an altitude of 48 m. It is approximately 12 km east of Algiers, with Oued El-Harrach running through it to the south. The ENSA Experimental Station spanned an area of 10 ha. For our study, we designated an experimental plot of roughly 200 m^2, cultivated in open fields (*Fig. 1*). The climate in the study area is Mediterranean, with average temperatures ranging between 15°C and 20°C per day. Winters are generally mild, although occasional frosts may occur, whereas summers are characterized by a period of drought.

Environmental conditions of study season

Climate plays a fundamental role in natural environments by influencing the ecological characteristics of ecosystems, including temperatures (T°), precipitation (P) and relative humidity (RH). *Table 1* presents the climate data (temperatures, relative humidity and precipitation) for the months of December to April, collected at the ENSA weather station. In December, temperatures ranged from 7.2°C (min) to 15.5°C (max), with an average of 11.4°C, while the average relative humidity was 84.2% and precipitation reached 125.2 mm. In January, temperatures increased slightly, with an average of 12.4°C, and precipitation decreased to 64.5 mm. In February, average temperatures continued to increase (14°C), with precipitation of 59 mm. In March, average temperatures reached 14.7°C, and precipitation decreased further to 37.2 mm. In April, temperatures continued to rise, with an average of 16.7°C, and precipitation was 31.2 mm. The total precipitation over this period was 317.1 mm. These data show a trend of progressively increasing temperatures and decreasing precipitation over the months, reflecting a shift to warmer and drier conditions in spring. These climate variations may have important implications for ecosystems and agricultural practices, particularly in terms of water management and crop adaptation.

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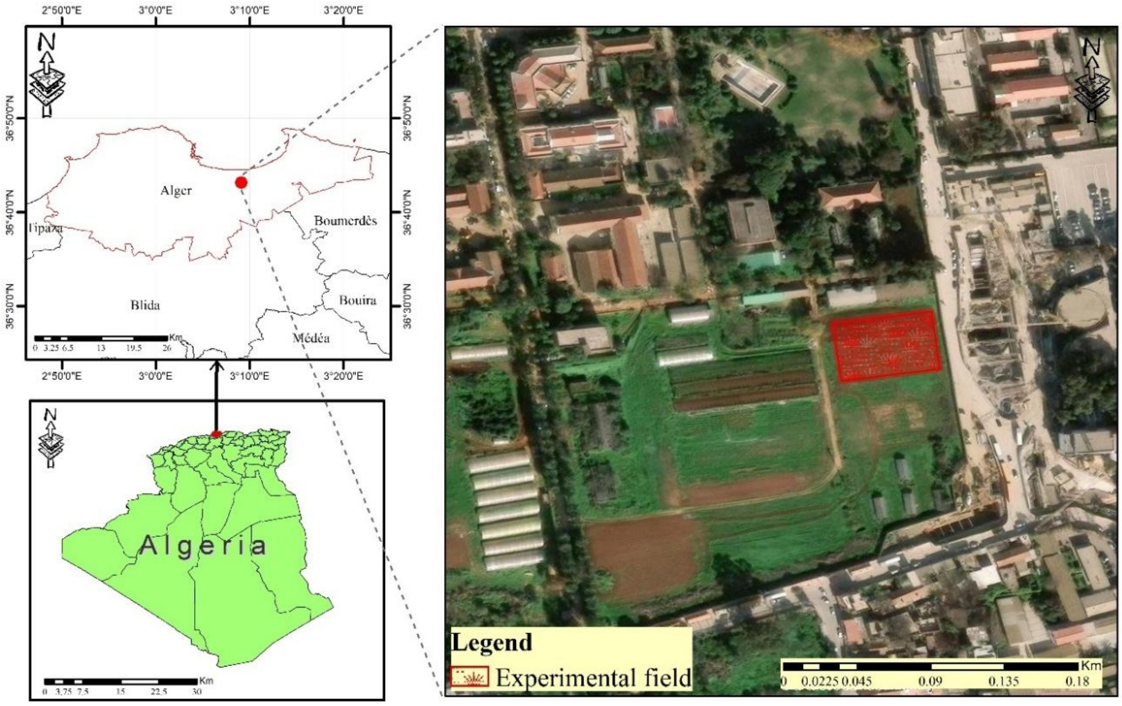

Figure 1. *Location of study area*

Table 1. *Climate data during the trial period*

Climate data	**T° (°C)**			**RH (%)**			**P (mm)**
Month	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	
December	7.2	15.5	11.4	72.1	96.4	84.2	125.2
January	7.8	16.9	12.4	73.9	94.1	84	64.5
February	9.5	18.6	14	62.4	88.6	75.5	59
March	10.9	18.5	14.7	67.3	91.2	79.2	37.2
April	12.4	21.1	16.7	74.7	94.5	84.6	31.2
Total precipitation sum							**317.1**

Source: ENSA weather station

Tillage and sowing

The experimental field was ploughed on 6/10/2019 with a share plough to a depth of around 30 cm. Surface cultivation was carried out on 12/12/2019 using a cover crop. Sowing was carried out manually on 12/13/2019 in stacks of 3 seeds each. Sowing depth was around 5 cm. The spacing chosen was 80 cm between rows and 30 cm between seeds, giving 5 rows/elemental plot, 15 seeds/row. Sowing density is 10 plants/m^2, corresponding to 100806 plants/ha. The seeding rate is therefore 148 kg/ha.

Plant material

The plant material used in the trial is the "HISTAL" variety of broad bean (*Vicia faba* major). According to Hadjout and Zouidi (2024), this variety, originally from

Spain, was homogeneously developed from the "Aguadulce" population variety. It is semi-early, maturing three to four days before the "Aguadulce" variety. It has good resistance to cold conditions. The plant is tall, with four to five strong, thick stems. The leaves were large with oval leaflets. The pods were extra-long, measuring 30–33 cm in length and 3 cm in width, and contained 7–8 grains. The varietal purity was 98% and the germination rate was 85%. The average dry weight of a hundred kernels was 147 g.

Experimental design

The investigation focused on a single aspect, which was the method of phosphate fertilization, and a single controlled or random variable, which was the block. We employed a randomized complete block design consisting of four replications or four blocks. Each block comprised four elementary plots representing four different treatments. The blocks were positioned perpendicular to the slope gradient, and the individual plots were aligned in the direction of the gradient. In total, our trial consisted of 16 elementary plots, each measuring 1.75 m wide and 4.25 m long, resulting in a surface area of 7.44 square meters. Blocks and individual plots were spaced 1 m apart from one another. *Figure 2* illustrates the experimental setup, displaying the arrangement of the blocks and individual plots in the field.

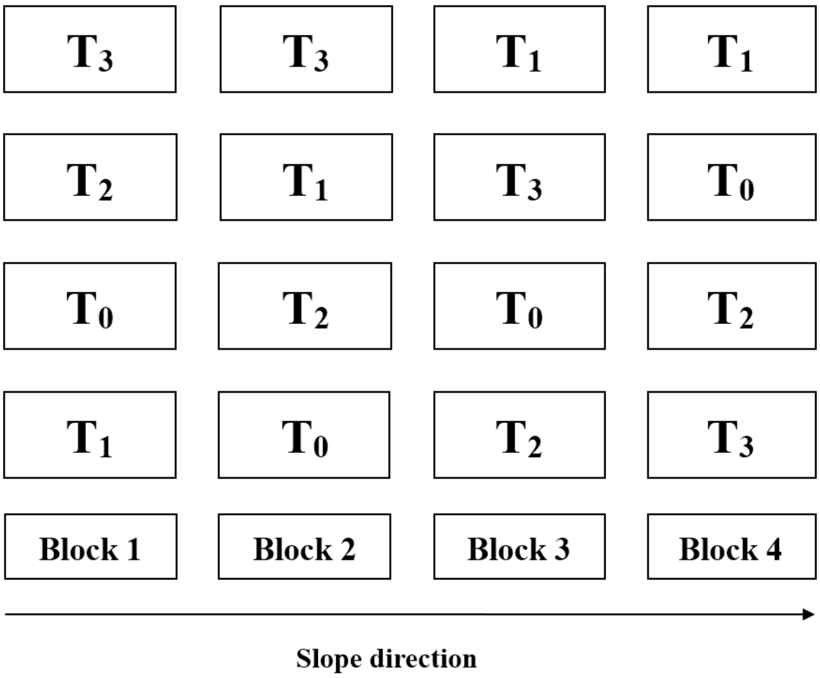

***Figure 2.** Summary diagram of the experimental set-up in the field*

Phosphorus fertilization

Nitrogen, phosphorus, and potassium fertilizers were applied before sowing to ensure adequate plant nutrition. The quantities applied were 166 units of P_2O_5/ha, 100 units of K_2O/ha, and 40 units of N/ha. These quantities corresponded to the following basic inputs: 360 units of TSP/ha (7.2 units of TSP/200 m^2), 200 units of K_2SO_4/ha (4 units of K_2SO_4/200 m^2), and 100 units of urea/ha (2 units of urea/200 m^2). These doses were determined based on soil analyses to restore initial soil fertility. Physico-chemical

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analyses revealed that the soil was of the clay-loam type. Furthermore, laboratory analyses showed a low phosphorus content, evaluated at 77.6 ppm, whereas the standard for this type of soil, according to the Joret-Hebert method, is 243.6 ppm. Phosphate fertilizers were therefore added upstream to correct this deficiency. After this correction, the quantities of phosphate fertilizer applied to each elementary plot were as follows: T_0, no phosphate fertilizer applied (control). T_1: Soil application of 60 units of P_2O_5/ha in the form of super triple phosphate at 46% P (TSP) before sowing. T_2: Foliar application of 5 L/ha of Agriphos-type foliar fertilizer, divided into two applications: 2.5 L/ha at the two- to three-leaf stage, and 2.5 L/ha ten days later. T_3: Combined treatment: 60 units of P_2O_5/ha of TSP before sowing and 5 L/ha of foliar Agriphos in two applications, as mentioned above. These different methods of applying phosphate fertilizers were used to assess their effectiveness on the studied crops. The proposed doses take into account, on the one hand, the levels of P available in the soil and, on the other, the need to define reasonable doses in relation to the plant's optimum needs. This approach made it possible to evaluate the most suitable application method for beans, without using a combination of different P levels.

Biometric measurements

Biometric measurements of beans are performed at two key stages: flowering and physiological maturity of pods.

Flowering stage

At this stage, the only parameter measured was the number of branches per plant. For each elementary plot, 10 plants were randomly selected to perform the measurements. This allowed us to assess and compare the development of plant branches among different plots.

Physiological pod maturity stage

The performance elements and various crop yield components were assessed in the field by examining ten randomly selected plants in each elementary plot. The parameters measured at this stage are as follows:

- Final height of main stem (cm)
- Number of total pods per plant
- Number of seeds per pod
- Fresh weight of 1000 seeds (g)
- The theoretical fresh grain yield (qx/ha), was calculated using the following equation: Theoretical yield (g/m^2) = (Number of plants/m^2 × Number of pods/plant × Number of seeds/pod × Weight of 100 seeds) / 100
- The real fresh grain yield (qx/ha) was obtained using the weight of grains collected from 10 randomly selected plants in each elementary plot, covering an area of one m^2
- The fresh pod yield (qx/ha) was determined by measuring the total weight of all pods harvested from the 10 plants selected to calculate the actual fresh pod yield
- Aboveground dry matter yield (qx/ha)
- Dry weight of 1000 grains (g)

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Statistical analysis

Two-way analysis of variance was performed using SAS 9.2 (Statistical Analysis System) software to assess the effects of the phosphate fertilization methods and blocks. Mean comparisons were performed using the Newman-Keuls test, with a significance threshold of 5% ($\alpha = 0.05$).

Results and discussion

Morphological characteristics of broad bean

Number of branches per plant

The analysis of variance indicates that the different phosphate treatments do not have a statistically significant effect on the number of branches per plant ($p > 0.05$; *Table 2*). Nevertheless, it is worth noting that the T_0 treatment yielded the highest average, with 3.5 branches per plant, while the T_1 treatment resulted in the lowest average, at 3.17 branches per plant (*Table 2*). Yasmin et al. (2020) during their study on Faba bean response to phosphorus fertilization mentioned that the application of 40 kg P ha^{-1} produced higher results on yield components and yield such as the number of branches $plant^{-1}$ (8.33). Likewise, Zebire and Gelgelo (2019) indicated that the effect of phosphorus significantly increases the number of branches $plant^{-1}$ of *Phaseolus vulgaris* L. This allows us to deduce that the branching characteristic in our study can be attributed to the plant's genetic potential. For more reliable conclusions, further studies are essential. This should include expanding the sample size and conducting additional experimental repetitions. These measures will help minimize errors and validate the findings obtained.

Final height of the main stem

Analysis of variance revealed that the effect of the different treatments studied on the final height of the main stem of the bean was not statistically significant ($p > 0.05$; *Table 2*). However, it should be noted that the highest average value was obtained with the T_0 treatment, which shows an average height of 95.75 cm, while the T_1 treatment presents the lowest average value, with an average height of 92.30 cm (*Table 2*). In their research on cowpea cultivation, Nkaa et al. (2014) found that applying phosphorus fertilizer significantly enhanced several growth attributes, including plant height. This could be attributed to the fact that phosphorus is required in large quantities in shoot and root tips where metabolism is high and cell division is rapid (Ndakidemi and Dakora, 2007). On the other hand, some studies have reported that P did not have any significant effect on plant height when the plants are exposed to water stress, or when different forms of P fertilization are applied to the plants (Oukaltouma et al., 2021; Hashemabadi, 2013). This is because of the dryland conditions, or the fact that the environment was not favorable for the growth and response of faba bean to P fertilization. In addition, plant height is a characteristic that is affected by the environment, as was shown in a previous study (Papastylianou et al., 2021).

Number of total pods per plant

Based on the data presented in *Table 2,* it is evident that the total number of pods per plant varies with different doses of phosphorus. The T_3 treatment demonstrates the

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highest performance, with an average of 6.12 pods per plant, marking an 8.17% increase over the control. Conversely, the T_1 treatment shows a lower average, with only 3.87 pods per plant (*Table 2*). This can be attributed to the effective absorption and translocation of phosphorus applied to foliar during the vegetative stage, which likely contributed to an increased number of pods per plant (Mannan, 2014). These findings are consistent with the results observed by Solaiappan et al. (2002) in red gram. In addition, Fouda (2017) investigated the impact of various phosphate fertilizer doses on faba bean productivity and found that applying P-fertilizer to the soil at rates of 50%, 75%, and 100% of P_2O_5 significantly increased the average number of pods per plant. Our results demonstrate an increase in the number of pods per plant when using a combined treatment of phosphate fertilization applied both foliar and to the soil. Nevertheless, despite these observed variations, the study found no significant impact of different phosphorus treatments on the total number of pods per faba bean plant ($p > 0.05$; *Table 2*). While phosphorus remains crucial for plant growth, other factors may play a more significant role in pod production. Further research is needed to explore these additional variables and their effects.

Table 2. *Effect of phosphorus levels on morphological traits of broad bean*

	***P*-Level**	**Number of branches per plant**	**Final height of main stem (cm)**	**Number of total pods per plant**	**Number of seeds per pod**
Treatments	T0	3.50	95.75	5.62	5.93
	T1	3.17	92.30	3.87	6.53
	T2	3.37	92.90	4.75	6.43
	T3	3.42	92.77	6.12	6.42
p-values	Treatments	0.648	0.637	0.158	0.163
	Blocks	0.097	0.472	0.814	0.823
VC (%)		10.93	4.36	26.29	5.74

This table records the average values; the p-value of the Ficher test is presented with its significance level of 5% ($p > 0.05$: absence of statistical significance; "$p \leq 0.05$; $p \leq 0.01$; $p \leq 0.001$: Presence of statistical significance"). T_0: No phosphate fertilizer input (control test); T_1: Soil application of 60 Units of P_2O_5/ha in the form of super triple phosphate at 46% P (TSP) before sowing; T_2: Application of an Agriphos-type foliar fertilizer using a dose of 5 l/ha which is divided into two parts: 2.5 l/ha sprayed at the two to three leaf stage of the plant and 2.5 l/ha applied ten days after the first spray; T_3: Combined treatment between T_1 and T_2. CV: Variation Coefficient

Number of seeds per pod

The analysis of variance revealed that the different treatments studied had no significant effect on the number of seeds per pod ($p > 0.05$; *Table 2*). These findings are consistent with the results reported by Negasa et al. (2019) for faba bean varieties in Southeastern Ethiopia. Similarly, Bolland et al. (2000) found that different levels of P application on faba bean did not significantly affect the number of seeds per pod. However, the results obtained were almost identical for treatments T_2 and T_3, with a slight increase compared to the control (T_0). Treatment T_1 recorded the best value, with an average of 6.53 seeds per pod, representing an increase of 9.18% compared to the control (*Table 2*). Kubure et al. (2016) found that phosphorus application tended to improve seeds/pod when compared with no phosphorus. Similar results were observed in our study. However, it is important to note that the number of seeds per pod was

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lower than the typical range of seven to eight seeds per pod. This reduction may be attributed to the presence of a significant number of empty pods in the crop. These empty pods likely resulted from insufficient rainfall during the grain-filling period. Also, phosphate can readily be rendered unavailable to plant roots as it is the most immobile of the major plant nutrients (Dikr and Abayechaw, 2022).

Grain yield and yield attributes

Hundred grain fresh weight

The variance analysis indicates no significant differences in the effect of the different methods of phosphate fertilization on the fresh weight of one hundred grains ($p > 0.05$; *Table 3*). However, despite the absence of significant differences, it is interesting to note a trend towards a progressive increase in this parameter was observed between the different treatments used. Indeed, the fresh weight of one hundred grains increased from 195.5 g for treatment T_0 to 235.5 g for treatment T_3, which displays the highest value, an increase of 16.98% compared to the control (*Table 3*). Phosphorus application caused to increase in the hundred-grain weight and grain yield of the faba bean (Hashemabadi, 2013). In addition, Madzivhandila et al. (2012) noted during their studies on four chickpea cultivars an increase in grain yield with P fertilizer application which was associated with greater crop biomass and 100-seed weight at 45 and 90 kg P/ha compared with the control. Furthermore, an increase in grain yield, shoot biomass, number of seeds per pod, and 100-seed weight of chickpea with an increase in P rate was reported in Iran (Khorgamy and Farnia, 2009). Moreover, Hamayun et al. (2011) observed that applying NPK both through soil and foliar methods resulted in the highest thousand seed weight for lentil plants. This finding aligns with our results, which also showed that combined treatments of phosphorus fertilization yielded the highest values.

Theoretical fresh grain yield

The statistical analysis indicates a significant difference in the theoretical yield of fresh grains among the various treatments (($p \leq 0.05$; *Table 3*). Specifically, treatments T_2, and T_3 resulted in notably higher theoretical yields compared to the control, while treatment T_1 yielded significantly less, with an average of 53.32 qx/ha. In contrast, treatment T_3 achieved the highest yield, averaging 91.86 qx/ha (*Table 3*). This represents an impressive 28.89% increase over the control. These findings underscore the positive impact of the T_3 treatment on fresh grain yield, distinguishing it as the most effective among the treatments tested. According to Mihoub and Boukhalfa-Deraoui (2014), the addition of phosphate fertilizer significantly influenced grain yield and its components. In addition, Belaid (2013) noted that the Phosphorus inputs constitute a primary factor in improving the yield of winter cereals. On the other hand, Ben Aissa (2018) found that fertilizer application methods significantly impact estimated returns, with localized and mixed treatments yielding the highest results—averaging 60 qx/ha—while bottom application produced the lowest yield at 41.36 qx/ha. The data indicates that localized and mixed methods are more effective in enhancing yield due to the higher availability of phosphate ions for plant nutrition. Our study showed similar results, especially for the bottom and combined treatments. These results indicate that the mixed treatment effectively enhances yield compared to other methods, due to the increased availability of phosphate ions for plant nutrition.

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***Table 3.** Effect of phosphate fertilization modes on bean yield characteristics*

	P-Level	Hundred grain fresh weight (g)	Theoretical fresh grain yield (q ha^{-1})	Real fresh grain yield (q ha^{-1})	Fresh pod yield (q ha^{-1})	Aerial dry matter yield (q ha^{-1})	Hundred grain dry weight (g)
Treatments	T_0	195.5	65.32^b	52.6	187.60	58.45	105.71
	T_1	210.5	53.92^a	42	157.25	57.74	119.12
	T_2	235.0	69.99^b	45.6	169.80	56.15	124.65
	T_3	235.5	91.86^c	56.95	205.15	59.08	114.17
p-values	Treatments	0.173	**0.033**	0.169	0.309	0.596	0.345
	Blocks	0.103	0.138	0.019	0.125	0.021	0.686
VC (%)		12.39	21.27	18.85	19.76	5.36	12.36

This table records the average values; the *p*-value of the Ficher test is presented with its significance level of 5% ($p > 0.05$: Absence of statistical significance; "$p \leq 0.05$; $p \leq 0.01$; $p \leq 0.001$: Presence of statistical significance"). T_0: No phosphate fertilizer input (control test); T_1: Soil application of 60 Units of P_2O_5/ha in the form of super triple phosphate at 46% P (TSP) before sowing; T_2: Application of an Agriphos-type foliar fertilizer using a dose of 5 l/ha which is divided into two parts: 2.5 l/ha sprayed at the two to three leaf stage of the plant and 2.5 l/ha applied ten days after the first spray; T_3: Combined treatment between T_1 and T_2. CV: Variation Coefficient

Real fresh grain yield

According to the results of the analysis of variance, no significant differences were observed between the different treatments applied in terms of real fresh grain yield ($p > 0.05$; *Table 3*). However, a closer look at the data in *Table 3* shows that treatment T_3 generated the highest yield among the treatments, with an average of 56.95 qx/ha. This represents an increase of 7.63% compared to the control. On the other hand, the T_1 treatment recorded a relatively low yield, with only 42 qx/ha compared to the control (*Table 3*). The results of Ben Aissa (2018) highlight the important role of localization and mixed treatment in improving the productivity of wheat cultivation and maintaining a level of plant-friendly phosphate nutrition. The application of essential minerals through foliar fertilization can sustain the photosynthesis rate for an extended period, potentially leading to increased grain yields (Gonçalves et al., 2017). Furthermore, Ling and Silberbush (2002) suppose that foliar fertilization serves primarily as a supplementary method, which helps in addressing deficiencies in fully-grown plants. However, it should not replace soil fertilization for major nutrients but rather complement it. Ultimately, our study demonstrated the potential benefits of phosphorus-based combined fertilization. However, it also highlighted the need for further research to explore optimal application periods, doses, and the impact of soil phosphorus availability on crop performance.

Fresh pod yield

The results of the analysis of variance indicate that the effect of the different treatments studied on the yield of fresh pods is not statistically significant ($p > 0.05$; *Table 3*). Despite the absence of statistically significant differences, a clear increase in the yield of fresh pods was observed between the different treatments applied. The T_3 treatment stands out with the highest yield, reaching an average of 205.15 qx/ha, while the T_1 treatment presents the lowest yield, with an average of 157.25 qx/ha (*Table 3*). Phosphorus application improved some yield attributes taken into consideration in the

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study of Nkaa et al. (2014) on cowpea such as pod fresh weights, this conforms with the findings of other workers (Haruna and Usman, 2013; Nyoki and Ndakidemi, 2013; Singh et al., 2011; Ndor et al., 2012) who also discovered a significant increase in yield of cowpea in response to phosphorus application. In addition, Hamayun et al. (2011) quoted that the maximum total pod weight per plant of lentil (6.83 gm/plant) was recorded when NPK was supplied both through foliar as well as soil application in the form of a single dose. This aligns perfectly with our results. However, Agboola and Obigbesan (1981) reported that phosphorus application did not significantly increase cowpea yield but rather enhanced nodulation and phosphorus content of the leaf and stem. In light of these results, our findings suggest that yield components are polygenic traits, governed by multiple factors, both genetic and environmental.

Aerial dry matter yield

The results of our study show that the dry weight of the aerial parts (stems and leaves) exhibited only minor variations among the different treatments. Specifically, there was a slight decrease in dry weight from treatment T_0 to treatment T_2. In contrast, treatment T_3 resulted in a notable increase in dry matter yield, with an enhancement of 1.06% compared to the control, equating to a yield of 59.08 qx/ha (*Table 3*). Essential plant nutrients are mainly applied to soil and plant foliage to achieve maximum economic yields. The soil application method is more common and most effective for nutrients, which are required in higher amounts. However, under certain circumstances, foliar fertilization is more economical and effective (Fageria et al., 2009). Our results show that the most effective fertilization method was the combined fertilization. This suggests that it would be advisable to reassess the phosphorus doses applied for non-combined methods, as they may be insufficient. Statistical analysis reveals no significant differences in aerial dry matter yield among the various treatments ($p > 0.05$; *Table 3*). The research conducted by Nkaa et al. (2014) demonstrated that phosphorus application had a significant impact on the total aboveground dry matter of the three cowpea varieties studied. Similarly, Turuko and Mohammed (2014) found significant differences in dry matter yield among various phosphorus rates (0, 10, 20, 30, and 40 kg ha^{-1}) applied to common beans. The results underscore the importance of phosphorus fertilization in enhancing dry matter yield across different crops. Regarding our study, this suggests that the effect of phosphorus on aboveground dry matter yield may be limited or influenced by other environmental or cultural factors.

Hundred-grain dry weight

The analysis of the variance of the dry weight of one hundred grains revealed no significant difference between the different treatments studied ($p > 0.05$; *Table 3*). However, it is interesting to note a trend toward an increase in dry weight of one hundred grains in treatments T_1, T_2, and T_3 compared to the control. Indeed, the T_2 treatment stands out by displaying the highest dry weight of one hundred grains, with 124.65 g, an increase of 15.19% compared to the control (*Table 3*). Plants can absorb essential elements through their leaves. The absorption takes place through their stomata and also through their epidermis. More recently, foliar feeding has been widely used and accepted as an essential part of crop production. Although the benefits of foliar feeding have been well documented and increasing efforts have been made to achieve consistent responses (Patil and Chetan, 2018). Nutrients applied to the foliage are

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generally absorbed more rapidly than when applied to the soil. Foliar application provides a means of quickly correcting plant nutrient deficiencies, when identified on the plant. It often provides a convenient method of applying fertilizer (Rajasekar et al., 2017). It should also be noted that this dry weight is lower than the initial dry weight of 147 g used during sowing. This decrease could be explained by unfavorable climatic conditions during the formation and filling of grains, in particular a deficit of precipitation. environmental and seasonal factors, as well as the choice of doses and methods of application of phosphate fertilizers, are all important factors that could influence the results (Hadjout and Zouidi, 2024).

Conclusion

The present study was conducted under Mediterranean climate conditions to investigate the effect of three phosphate fertilization methods on broad bean cultivation. The main objective was to assess the influence of these fertilization methods on both plant morphological characters and the different yield components. The results reveal that morphological traits are not significantly influenced by the different phosphate fertilization methods applied. This suggests that, in terms of appearance and plant structure, the different phosphate fertilization methods do not play a major role. Regarding yield components, it was found that phosphate fertilization had a significant effect only on the theoretical fresh grain yield. Specifically, the combined fertilization method (T_3) led to the highest theoretical fresh grain yields, while the foliar phosphate fertilization (T_2) produced intermediate yields between the other two methods (T_1 and T_3). To delve further into these conclusions, it is recommended to conduct additional research on other plant species that are more sensitive to phosphorus availability, using different levels of this nutrient. This would help to better understand the effects of phosphate fertilization on crops more responsive to phosphorus. It would also be interesting to conduct the study under controlled irrigation conditions to evaluate the interactions between phosphate nutrition and water supply. These factors are crucial for ultimately understanding and maximizing the production potential of the crop by leveraging different phosphorus doses used.

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Conflict of interests. The authors declare no conflict of interests to report regarding the present study.

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