Zagazig J. Agric. Res., Vol. 52 No. (1) 2025 21-36

Plant Production Science

Available online at http://zjar.journals.ekb.eg
http:/www.journals.zu.edu.eg/journalDisplay.aspx?Journalld=1&queryType=Master

IMPACT OF HUMIC ACID AND PHOSPHORUS LEVELS ON YIELD AND PHOSPHORUS USE EFFICIENCY IN FABA BEAN CULTIVATED UNDER SANDY SOIL CONDITIONS

Ahmed S.M. El-Kholy* **and Eman A. Mohamed**

Agron. Dept., Fac. Agric., Zagazig Univ., Egypt

Received: 17/11/2024; Accepted: 03/01/2025

ABSTRACT: Efficient phosphorus use in faba bean production is critical for sustainable agriculture particularly in sandy soils with low nutrient availability. The present study aimed to assess the influences of different levels of humic acid (HA) and phosphorus (P) fertilizer on phosphorus use efficiency and faba bean productivity under sandy soil conditions. Field experiment was conducted during two growing seasons of 2020/2021 and 2021/2022 at the experimental farm of the Faculty of Agriculture, Zagazig University, El-Khattara, Sharkia Governorate, Egypt. Faba bean plants were treated with three HA levels: control (H0), 3 kg HA/Fad.. (H1), and 6 kg HA/Fad.. (H2), and four phosphorus levels: control (P0), 12.5 kg P_2O_5/fad.. (P1), 25 kg P_2O_5/Fad.. (P2), and 37.5 kg P_2O_5/Fad. (P3). The highest HA level (6 kg HA/Fad.) produced the maximum seeds per plant, number of pods and seed weight per plant, 100-seed weight, total phosphorus uptake, and phosphorus uptake efficiency (PUPE). Combined analysis of two seasons indicated that HA application at 3 kg/Fad. significantly increased seed yield per Fad., harvest index (HI), and phosphorus use efficiency (PUE). However, phosphorus utilization efficiency (PUZE) decreased by increasing HA levels. Phosphorus harvest index (PHI) was unaffected by HA levels. Increasing P levels up to 37.5 kg P_2O_5/Fad. significantly enhanced number of pods and seeds, seed weight per plant, 100-seed weight, seed and biological yield per Fad., HI, and total phosphorus uptake. Notwithstanding, higher P levels led to reductions in PHI, PUPE, PUZE, and PUE.

Key words: Faba bean, phosphorus uptake efficiency, phosphorus use efficiency, phosphorus utilization efficiency, nutrient availability, soil fertility, yield improvement, sustainable agriculture

INTRODUCTION

Faba bean (*Vicia faba* L.) is one of the most important leguminous crops for human nutrition in Egypt. While it is widely consumed as a staple food in developing countries, in industrialized nations, it also serves as a valuable source of animal feed (**Kasem, 2012**). In 2022, Egypt harvested 63,877 Fad. of faba bean, with an average yield of 1.615 tons per Fad.. However, Egypt faces a significant gap between local production and consumption, necessitating the import of approximately 334,173 tons of faba beans (**FAOSTAT, 2022**).

Humic acid (HA) is one of the most active components of soil organic matter, known to enhance the biological, chemical, and physical properties of soil (**Taha and Osman, 2017**). It promotes root growth and development in crops like faba bean (**Akinci *et al.,* 2009**), improves soil fertility, and increases nutrient availability by retaining nutrients on its surfaces. Additionally, HA enhances water retention and provides pH buffering, contributing to overall soil health (**El-Guibali *et al.,* 2016**). In this perspective, **Al-Azze *et al.* (2023)** demonstrated that application of HA at level of 40 kg/ha significantly increased seed weight per plant and phosphorus concentration in seeds. Similarly,

* **Corresponding author: Tel.:** +201114850845
E-mail address: ahmed.elkholy.agronomy@gmail.com

Awaad *et al.* (2020) found that addition of HA to faba bean plants at rate of 10 kg/Fad. significantly improved number of pods per plant, number of seeds per pod, seed and biological yields/Fad., harvest index and total P utake.

Phosphorus (P) is one of the irreplaceable nutrients for plant growth and yield, playing a critical role in nodulation and biological nitrogen fixation, root and nodule development, and the formation of phosphoglycolate required for photosynthesis (**Oukaltouma *et al.*, 2021; Baccari *et al.*, 2024**). **Kubure *et al.* (2016)** found that elevating P levels up to 46 kg P_2O_5 ha^{-1} substantially enhanced 100-seed weight, pod weight per plant, and both seed and biological yields per hectare. Similarly, **Lal *et al.* (2016)** reported maximum total P uptake and seed yield with 90 kg P_2O_5 ha^{-1}. Despite its importance, many arid and semi-arid agricultural soils suffer from P deficiency due to the high P fixation capacity of these soils, illustrating extensively applied P unavailable to plants (**El-Etr *et al.*, 2011**). Soluble P fertilizers, though essential, often interact with soil components like calcium, forming insoluble compounds and further limiting P availability (**Awaad *et al.*, 2020; Oukaltouma *et al.*, 2021**). It is vital to apply P fertilizers at optimal levels and select crop varieties with high phosphorus use efficiency (PUE) to optimize yield, reduce production costs, and limit environmental pollution. **Daoui *et al.* (2012)** demonstrated that reducing P levels from 120 or 80 to 40, and eventually to 0 kg P_2O_5 ha^{-1}, significantly increased PUE and phosphorus uptake efficiency (PUPE), while phosphorus utilization efficiency (PUZE) remained unaffected. In another study, **Nebiyu *et al.* (2016)** elucidated that increasing P levels from 0 to 30 kg P_2O_5 ha^{-1} considerably improved seed yield, total aboveground biomass, and phosphorus acquisition efficiency (PAE). However, harvest index (HI) and P utilization efficiency (PUE) were unaffected. Furthermore, **Papakaloudis and Dordas (2023)** found that a P application of 60 kg P_2O_5 ha^{-1} maximized seed yield per hectare, number of pods per plant, and PUE. This study aimed to identify the optimal levels of P and humic acid (HA) to maximize faba bean yield under a drip irrigation system in sandy soil conditions and enhancing PUE through HA application.

MATERIALS AND METHODS

Experimental Site and Treatments

This study was performed over two winter seasons of 2020/2021 and 2021/2022 at experimental farm of El-Khattara belongs to Faculty of Agriculture, Zagazig University, Egypt. The used faba bean cultivar was Nubaria 5 cv. Three levels of humic acid (0, 3, and 6 kg/Fad.) were applied as a commercial product, Ultra Humi Max, containing 80% humic acid, 10% fulvic acid, and 10% potassium. Humic acid was applied via fertigation in two equal doses: the first dose was administered 15 days after sowing (DAS), and the second dose was applied 30 days after the first. Additionally, four levels of phosphorus fertilizer (0, 12.5, 25, and 37.5 kg P_2O_5/Fad.) were used. Phosphorus was applied in the form of mono-calcium superphosphate granules (12.5% P_2O_5) and incorporated around the drip line prior to planting to ensure availability during early crop growth stages.

Experimental Design and Crop Management

The experiment was conducted using split-plot design with three replicates. The three humic acid (HA) levels were randomly assigned to the main plots, while the four phosphorus fertilizer levels were allocated to the sub-plots. Each sub-plot covered an area of 16 m^2, consisting of four drip irrigation lines, each 4 meters long, with a spacing of 1 meter between lines. Earlier to sowing, soil samples were collected from randomly selected locations within the experimental field at a depth of 0–30 cm. The soil properties are shown in Table 1. Meteorological data recorded during the two growing seasons are shown in Table 2. This information provided insights into the main environmental conditions and soil characteristics that could influence the growth and response of faba bean to HA and phosphorus treatments.

Sowing was conducted on November 5^{th} in the first season and November 9th in the second season. Faba bean seeds were sown on both sides of the drip irrigation line, with a spacing of 10 cm between hills. A standard nitrogen fertilizer dose of 20 kg N/Fad. was applied post-emergence in the form of urea (46.5% N). Potassium fertilizer, at a rate of 48 kg K_2O/Fad.

Table 1. Soil properties at experimental site for seasons of 2020/2021 and 2021/2022

Characteristics	2020/2021	2021/2022
Mechanical properties		
Sand (%)	88.40	89.50
Silt (%)	1.16	1.12
Clay (%)	10.24	9.11
Soil texture	Sandy loam	Sandy
Organic matter (%)	0.30	0.27
Chemical analyses		
Electrical conductivity (mmhose/cm)	0.90	1.30
pH	7.95	8.23
Available potassium (ppm)	36.64	36.06
Available phosphorus (ppm)	3.59	5.49
Total nitrogen (%)	0.007	0.009
Soluble cations (meq/100 g)		
Potassium	0.08	0.07
Sodium	0.60	0.90
Magnesium	0.11	0.14
Calcium	0.22	0.16
Soluble anions (meq/100 g)		
Chlorine	0.20	0.39
Carbonate	-	-
Bicarbonate	0.05	0.02
Sulphate	0.77	0.88

Table 2. Monthly maximum (MAX, C°), minimum (MIN, C°) and mean (MEAN, C°) temperature and relative humidity (RH, %) during two faba bean growing seasons

Month	2020/2021				2021/2022			
	Max	Min	Mean	RH	Max	Min	Mean	RH
Nov.	23.57	16.40	19.80	62.15	28.43	17.89	21.80	62.57
Dec.	22.42	11.94	17.22	59.66	20.56	11.22	15.40	59.79
Jan.	21.26	11.55	14.99	63.93	17.53	7.64	11.85	68.59
Feb.	22.07	11.64	14.55	62.70	19.50	8.54	13.56	68.94
March	23.74	12.26	15.80	64.52	20.71	9.26	13.90	61.82
April	29.23	14.27	20.46	51.82	30.60	16.07	22.60	45.53

as potassium sulfate (50% K_2O), was applied in three equal doses: the first dose post-emergence, the second at 50 days after sowing (DAS), and the third at 70 DAS. Weed control was managed manually through hand hoeing at 30 DAS. All other cultural practices followed the standard recommendations for faba bean cultivation. Harvesting was performed on April 12th and April 18th for the first and second seasons, espectively.

Measured Parameters

Agronomic traits

At harvest, 10 representative plants were selected from the second row of each sub-plot to assess agronomic traits, including number of pods and seeds per plant, seed weight per plant, and 100-seed weight. Additionally, all plants from the central two rows of each sub-plot were used to determine seed yield, biological yield, and harvest index.

Phosphorus efficiency traits

Seed and straw samples were oven-dried at 70°C for 48 hours to a constant weight, then ground and digested using sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2), following the procedure described by **Page *et al.* (1982)**. Phosphorus concentration in the digested samples was measured according to the modified method by **Ryan *et al.* (2001)**. Phosphorus uptake in seeds and straw was calculated by multiplying the P concentration in each by their respective yields per Fad.. Total phosphorus uptake was calculated as:

Total P uptake= Seed P uptake + Straw P uptake

Phosphorus harvest index (PHI) was measured as:

$$\text{PHI}=\frac{Seed\ P\ uptake}{Total\ P\ uptake}\times 100$$

according to **Nebiyu *et al.* (2016).**

Phosphorus uptake efficiency (PUPE) was defined as the total P uptake (kg P uptake) per P available in the soil (kg P available) according to **Moll *et al.* (1982).**

$$\textbf{PUPE}= =\frac{Totl P\ uptake}{P\ available}$$

Where:

P-available = P-available in the soil + P-added by fertilization

P-available in the soil= d × S × Z ×P(sol);

S: total area (1 Fad.)

d: dry bulk density (1.68 g/cm^3)

Z: rooting zone for nutrition (30 cm)

P(sol): represents P content as indicated by Olsen method (mg P/kg sol).

The estimated amount of P available in the soil was 7.70 and 11.75 kg P/Fad..

Phosphorus utilization efficiency (PUZE, kg seed/kg P) was defined as the seed yield per total P uptake as described by **Rose and Wissuwa (2012).**

$$\textbf{PUZE}=\frac{Seed\ yield}{Total\ P\ uptake}$$

PUE was calculated based on equation adapted from **Moll *et al.* (1982),** primarily used for nitrogen but also usable to phosphorus.

$$\textbf{PUE}=\frac{Seed\ yield}{P\ available}$$

Statistical Analysis

The analysis of variance (ANOVA) of each season and combined analyses across the two seasons were conducted according to the methods outlined by **Gomez and Gomez (1984)**. Mean comparisons were performed using Duncan's Multiple Range Test (**Duncan, 1955**) to identify significant differences between treatments. Statistical analyses were carried out using the ANOVA function of the Co-Stat software package, as per the protocol described by **Stern (1991)**. A combined analysis was performed for the data from both seasons after testing for error homogeneity using Bartlett’s test **(Steel *et al.*, 1997**).

RESULTS AND DISCUSSION

Number of Pods, Seeds and Seed Weight Per Plant

Effect of humic acid (HA)

As presented in Table 3, HA levels did not significantly impact number of pods, seeds per plant, or seed weight per plant in the second season.

Table 3. Effects of humic acid levels, phosphorus fertilizer levels, and their interaction on number of pods, number of seeds per plant, and seed weight per plant in faba bean for 2020/2021 and 2021/2022 seasons and combined analysis

Studied factors	Number of pods per plant			Number of seeds per plant			Seed weight per plant (g)		
	1st Season	2nd Season	Comb.	1st Season	2nd Season	Comb.	1st Season	2nd Season	Comb.
Humic acid level (H)									
Control (H0)	11.77 c	20.25	16.01 b	23.48	56.80	40.13 b	21.44 b	45.91	33.68 b
3 kg/Fad. (H1)	13.42 b	22.55	17.59 a	23.97	58.77	41.37 ab	23.54 ab	46.68	35.11 ab
6 kg/Fad. (H2)	14.35 a	23.32	18.83 a	24.90	62.86	43.88 a	24.47 a	48.76	36.62 a
F-test	**	NS	**	NS	NS	*	*	NS	*
Phosphorus fertilizer level (P)									
Control (P0)	10.94 c	16.23 c	13.59 d	19.00 d	43.96 d	31.49 d	17.73 d	36.08 c	26.81 d
12.5 kg P_2O_5/Fad. (P1)	11.67 c	21.00 b	16.33 c	23.10 c	58.73 c	40.92 c	21.63 c	45.18 b	33.41 c
25 kg P_2O_5/Fad. (P2)	12.88 b	22.57 b	17.72 b	24.40 b	65.14 b	44.77 b	24.66 b	48.39 b	36.52 b
37.5 kg P_2O_5/Fad. (P3)	17.23 a	28.37 a	22.80 a	29.96 a	70.08 a	50.02 a	28.81 a	58.82 a	43.81 a
F-test	**	**	**	**	**	**	**	**	**
Interaction:									
H×P	*	**	**	*	**	**	**	**	**

*, and ** signify significance at the 0.05 and 0.01 levels, respectively, while NS indicates non-significanc.

However, combined analysis across both seasons indicated that these traits significantly increased with HA application up to 6 kg HA/Fad.. These results align with findings by **Afifi *et al.*, (2010) and Al-Shareef *et al.* (2018),** who reported that HA improved soil structure, supported microbial growth, and enhanced plant growth and yield components in faba bean.

Effect of phosphorus (P) fertilizer levels

Across both seasons, increasing P fertilizer levels up to 37.5 kg P_2O_5/Fad. significantly enhanced number of pods, seeds, and seed weight per plant, as confirmed by the combined analysis (Table 3). These findings are consistent with those of **Kubure *et al.* (2016), El-Sobky and Yasin (2017), and Fouda (2017),** who observed that applying up to 75% of the recommended P fertilizer dose maximized number of pods and seeds and seed weight per plant. Increased phosphate ion availability in the soil promotes plant growth from early emergence through flowering and pollination (**Hosseinzadeh, 2005**).

Interaction effects

As illustrated in Fig. 1, the highest values for number of pods and seeds per plant, and seed weight per plant were achieved with the combined application of 6 kg HA/Fad. and 37.5 kg P_2O_5/Fad.. These findings are in agreement with **Al-Azze *et al.* (2023),** who reported that applying HA at 40 kg/ha and P at 160 kg/ha significantly increased seed weight per plant in Iraq. This analysis highlighted the potential for combined HA and P fertilizer applications to optimize yield components in faba bean, with specific interactions providing synergistic effects on pod and seed production.

100-Seed Weight, Seed Yield, And Biological Yield Per Fad.

Effect of humic acid (HA)

As shown in Table 4, humic acid (HA) levels had a significant impact on 100-seed weight and a highly significant effect on both seed and biological yield per Fad.. In the second season and combined data, the highest 100-seed weight

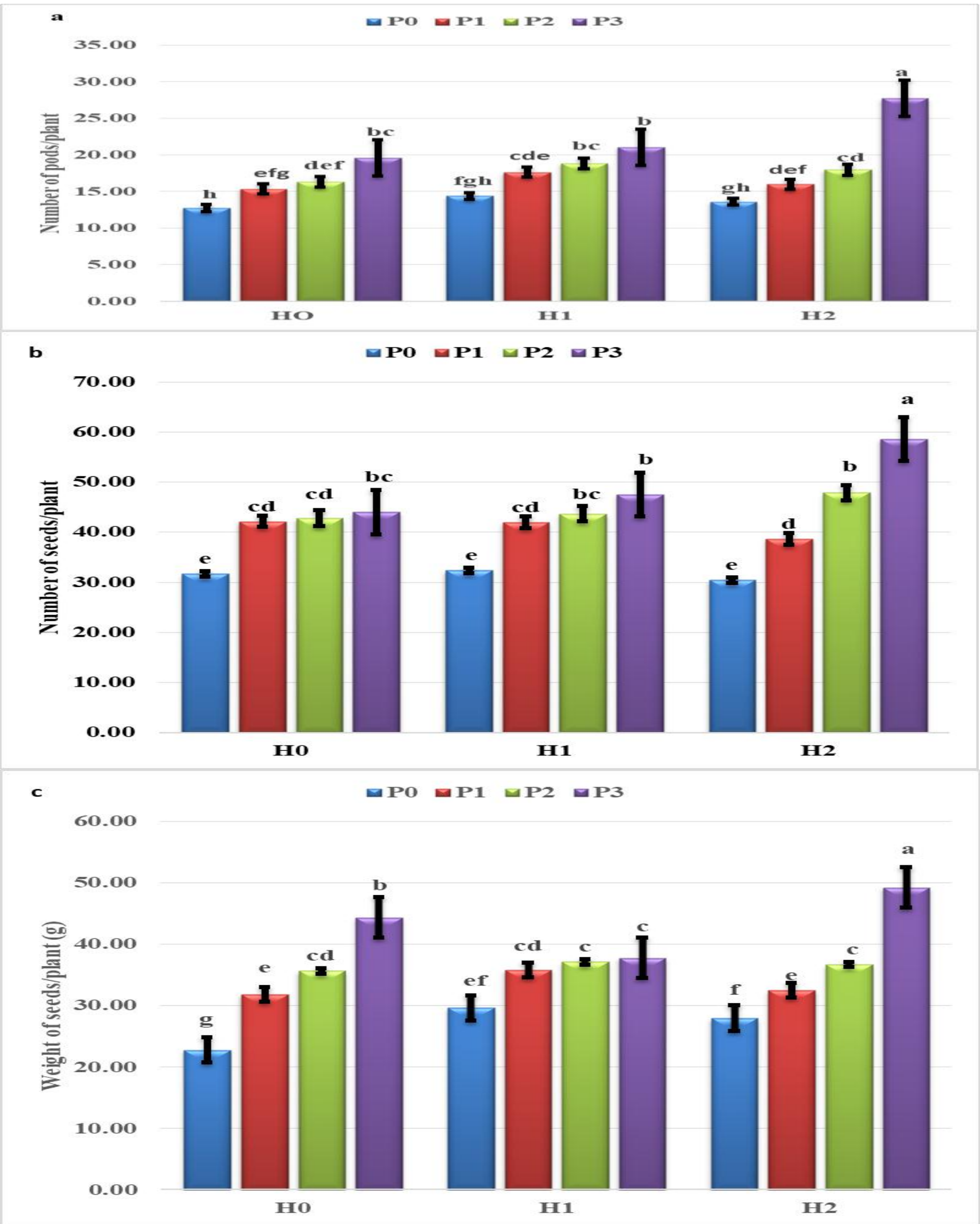

Fig. 1. Interaction effects of humic acid (HA) levels and phosphorus (P) fertilizer levels (combined data) on (a) number of pods/plant, (b) number of seeds/plant, and (c) seed weight/ plant. Error bars on the columns represent the standard error (SE), and treatments characterized with the same letter are not significantly different at $p < 0.05$. H0: control, H1: 3 kg HA/Fad., H2: 6 kg HA/Fad., P0: control, P1: 12.5 kg P_2O_5/Fad., P2: 25 kg P_2O_5/Fad., and P3: 37.5 kg P_2O_5/Fad.

Table 4. Effects of humic acid levels, phosphorus fertilizer levels, and their interaction on 100-seed weight, seed yield, and biological yield in faba bean for the 2020/2021 and 2021/2022 seasons, and combined analysis.

Studied factors	100-seed weight (g)			Seed yield (ardab/Fad.)			Biological yield (ton/Fad.)		
	1st Season	2nd Season	Comb.	1st Season	2nd Season	Comb.	1st Season	2nd Season	Comb.
Humic acid level (H)									
Control (H0)	75.76	79.11 b	77.43 b	7.837 b	13.641 b	10.760 b	2.220 b	6.172 b	4.200 c
3 kg/Fad. (H1)	78.13	79.67 ab	78.90 ab	11.048 a	15.528 a	13.288 a	2.802 a	6.393 ab	4.600 b
6 kg/Fad. (H2)	79.00	81.98 a	80.49 a	11.866 a	16.270 a	14.068 a	2.884 a	6.577 a	4.730 a
F-test	NS	*	*	**	*	**	**	*	**
Phosphorus fertilizer level (P)									
Control (P0)	71.21 c	76.42 d	73.81 d	8.470 d	12.349 d	10.410 d	2.296 c	5.708 c	4.002 d
12.5 kg P_2O_5/Fad. (P1)	75.11 bc	78.55 c	76.83 c	9.729 c	14.634 c	12.182 c	2.534 b	6.344 b	4.439 c
25 kg P_2O_5/Fad. (P2)	79.26 b	81.75 b	80.50 b	10.861 b	16.099 b	13.480 b	2.800 a	6.557 b	4.677 b
37.5 kg P_2O_5/Fad. (P3)	84.96 a	84.30 a	84.63 a	11.990 a	17.511 a	14.750 a	2.916 a	6.915 a	4.916 a
F-test	**	**	**	**	**	**	**	**	**
Interaction									
H×P	NS.	**	NS.	NS.	*	*	*	NS.	*

*, and ** signify significance at the 0.05 and 0.01 levels, respectively, while NS indicates non-significanc.

was achieved with the application of 6 kg HA/Fad.. Analyses of both seasons and combined confirmed that seed yield per Fad. responded positively to increasing HA levels, reaching an optimal response at 3 kg HA/Fad.. Furthermore, the combined analysis indicates that biological yield per Fad. increased significantly with HA levels up to 6 kg/Fad.. These findings align with those of **Afifi *et al.* (2010) and El-Kholy *et al.* (2019**). In addition **Roudgarnejad *et al.* (2021)** noted that HA enhanced biological yield by promoting plant growth through improved nutrient metabolism, enzyme activation, and changes in membrane permeability and protein composition, all of which contributed to increased plant biomass. HA is reported to stimulate root growth, thereby enhancing photosynthetic rates, nutrient uptake, leaf area, and overall plant biomass, which ultimately boosts yield (**Canellas *et al.*, 2015**).

Effect of phosphorus (P) fertilizer levels

The results in Table 4 exhibited that phosphorus (P) fertilizer levels had a highly substantial effect on 100-seed weight, seed yield, and biological yield across both seasons and in the combined analysis. The combined data indicated that increasing P fertilizer level up to 37.5 kg P_2O_5/Fad. substantially enhanced 100-seed weight as well as seed and biological yield per Fad.. In the first season, biological yield responded positively to P fertilizer levels up to 25 kg P_2O_5/Fad.. The observed increase in seed yield can be attributed to enhanced metabolic activity and an increased photosynthetic rate, which improves nutrient translocation to the developing seeds (**Lal *et al.*, 2016**). These findings are consistent with results reported by **Kubure *et al.* (2016), El-Sobky and Yasin (2017), and Fouda (2017),** who also observed yield improvements with increased P fertilization. **El-Safy *et al.*, (2021**) found that seed yield, 100-seed weight, and biological yield per Fad. in the first season significantly increased with P fertilization up to 15 kg P_2O_5/Fad., while seed and biological yield continued to increase up to 30 kg P_2O_5/Fad.. These results underscore the essential role of phosphorus in enhancing dry matter accumulation and leaf longevity, which in turn leads to improved dry matter production and overall plant yield (**Al-Azze *et al.*, 2023**).

Interaction effects

The interaction between HA and P fertilizer levels significantly impacted seed and biological yield per Fad. in the combined analysis, as shown in Fig. 2. However, 100-seed weight was not significantly affected by HA and P interaction

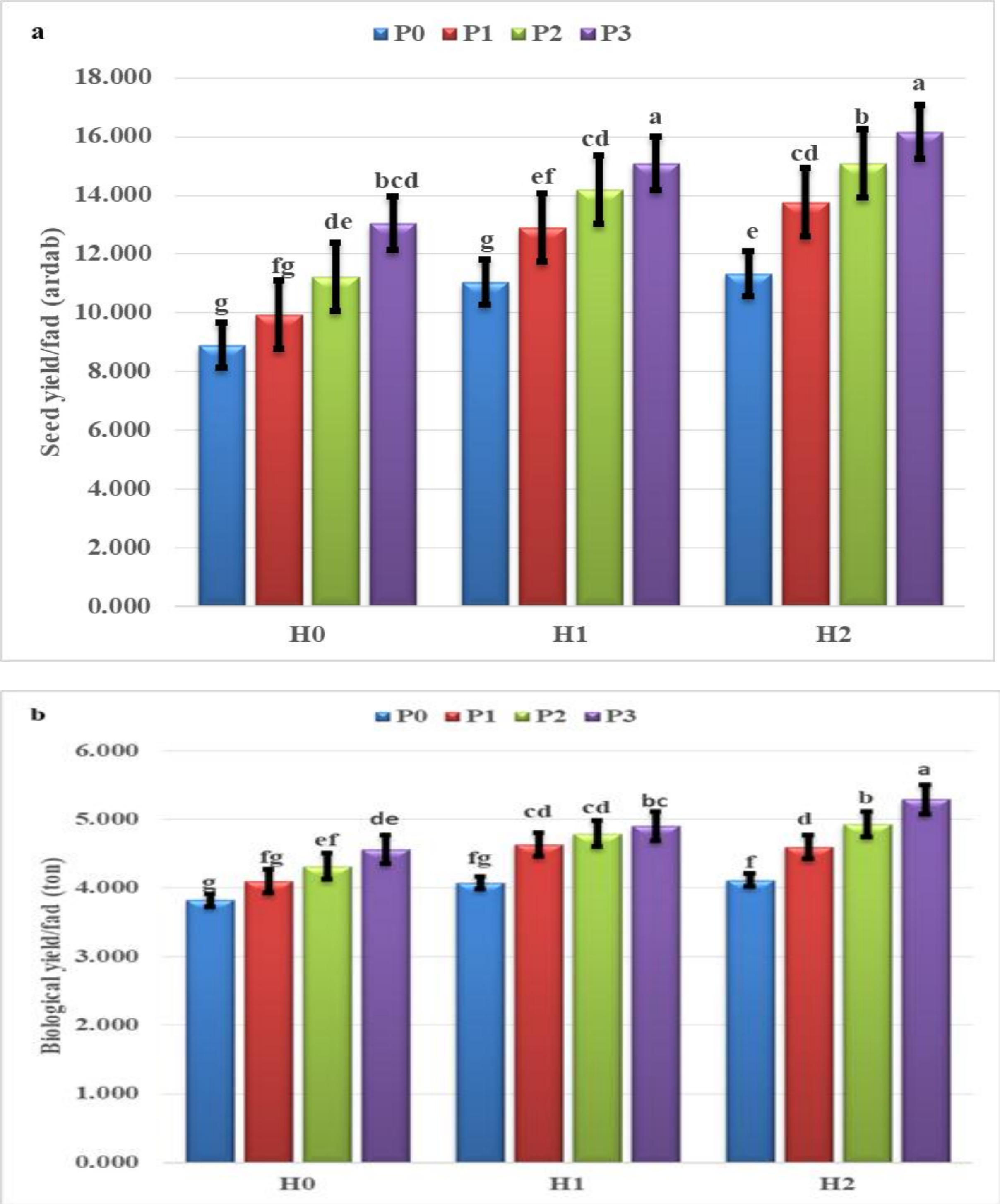

Fig. 2. Interaction effects of humic acid (HA) levels and phosphorus (P) fertilizer levels (combined data) on (a) seed yield per Fad. and (b) biological yield per Fad.. Error bars on the columns represent the standard error (SE), and treatments characterized with the same letter are not significantly different at $p < 0.05$. H0: control, H1: 3 kg HA/ Fad., H2: 6 kg HA/Fad., P0: control, P1: 12.5 kg P_2O_5/Fad., P2: 25 kg P_2O_5/Fad., and P3: 37.5 kg P_2O_5/Fad.

in the combined data. The results indicated that applying HA at rates of 3 or 6 kg/ Fad. along with 37.5 kg P_2O_5/Fad. significantly increased seed yield per Fad.. The highest biological yield per Fad. was achieved with the combination of 6 kg HA/Fad. and 37.5 kg P_2O_5/ Fad., significantly outperforming other treatment combinations. These findings are consistent with previous studies by **El-Kholy *et al.* (2019), Awaad *et al.* (2020), and Al-Azze *et al.* (2023),** who reported that combined applications of HA and P fertilizers enhanced yield attributes by improving nutrient availability and utilization in faba bean cultivation.

Harvest Index, Total Phosphorus Uptake And Phosphorus Harvest Index

Effect of humic acid (HA)

The results in Table 5 indicated that increasing HA levels from 0 to 3 kg/Fad. significantly improved harvest index (HI) in the first season and combined analysis. Similar results were reported by **Afifi *et al.* (2010), Awaad *et al.* (2020), and Roudgarnejad *et al.* (2021),** who observed sigmificant inccrememt in faba bean HI due to HA application. HA enhanced dry matter accumulation and efficient partitioning of assimilates between plant organs, which is essential for yield improvement. Furthermore, analyses of both seasons and combined revealed that increasing HA levels from 0 to 3 and then to 6 kg/Fad. led to significant increases in total phosphorus uptake. The addition of HA likely improved soil organic matter, thereby enhancing nutrient retention and stimulating microbial activity. This microbial activity facilitates the conversion of nutrients from organic to mineral forms, as reported by **Yousif *et al.* (2019)**. These findings align with those of **Awaad *et al.* (2020) and Fathy *et al.* (2023**). In contrast, PHI showed no significant response to varying HA levels across both seasons and in the combined analysis. While this finding differed from results reported by **Li *et al.* (2017)** where PHI increased significantly with HA application, it highlighted the potential variation in PHI response across different crop types and environmental conditions.

Table 5. Effects of humic acid levels, phosphorus fertilizer levels, and their interaction on harvest index (HI), total phosphorus uptake, and phosphorus harvest index (PHI) in faba bean for the 2020/2021 and 2021/2022 seasons, and combined analysis

Studied factors	Harvest index (HI, %)			Total P uptake (kg p/Fad.)			Phosphorus harvest index (PHI, %)		
	1st Season	2nd Season	Comb.	1st Season	2nd Season	Comb.	1st Season	2nd Season	Comb.
Humic acid level (H)									
Control (H0)	54.82 b	34.19 b	44.50 b	6.030 c	11.49 c	8.940 c	63.93	43.22	53.45
3 kg/Fad. (H1)	60.96 a	37.61 ab	49.29 a	8.643 b	14.01 b	11.327 b	67.40	44.48	55.94
6 kg/Fad. (H2)	6372 a	38.20 a	50.96 a	9.946 a	16.33 a	13.140 a	67.99	42.80	55.39
F-test	*	*	**	**	**	**	NS	NS	NS
Phosphorus fertilizer level (P)									
Control (P0)	56.70	33.63 c	45.16 c	3.686 d	6.17 d	4.928 d	71.53 a	49.19 a	60.36 a
12.5 kg P_2O_5/Fad. (P1)	58.93	35.69 bc	47.31 bc	6.502 c	11.51c	9.008 c	64.60 ab	41.54 b	53.06 b
25 kg P_2O_5/Fad. (P2)	59.97	38.05 ab	49.01 ab	10.079 b	16.65 b	13.363 b	62.70 b	40.85 b	51.78 b
37.5 kg P_2O_5/Fad. (P3)	63.75	39.30 a	51.52 a	12.559 a	21.93 a	17.244 a	66.61 ab	42.41 b	54.51 b
F-test	NS	**	*	**	**	**	*	**	**
Interaction:									
H×P	*	NS.	NS.	**	NS.	**	*	*	*

*, and ** signify significance at the 0.05 and 0.01 levels, respectively, while NS indicates non-significanc.

Effect of phosphorus (p) fertilizer levels

Results from the second season and combined analysis showed that faba bean plants fertilized with 37.5 kg P_2O_5/Fad. recorded the highest harvest index (HI) as presented in Table 5. **El-Safy *et al.* (2021)** depicted similar findings that increasing phosphorus fertilizer resulted in an enhanced harvest index. Conversely, studies by **Daoui *et al.* (2012), Kubure *et al.* (2016)** and **Nebiyu *et al.* (2016)** observed no significant impact of P levels on HI. Increasing P levels to 12.5, 25, and 37.5 kg P_2O_5/Fad. significantly increased total phosphorus uptake, corroborating findings from **Nebiyu *et al.* (2016)** and **Lal *et al.* (2016).** However, increasing P levels from 0 to 12.5, 25, or 37.5 kg P_2O_5/Fad. significantly decreased phosphorus harvest index (PHI) in the second season and combined analysis. Since factors influencing HI also impact nutrient use efficiency, PHI was identified as a key trait correlated with improvements in phosphorus yield and phosphorus utilization efficiency (PUZE) (**Daoui *et al.*, 2012**). These results are in consistent with those reported by **Nebiyu *et al.* (2016),** although a separate study by **Nebiyu *et al.* (2014**) showed no effect of P levels up to 30 kg P/ha on PHI.

Interaction effects

The interaction between HA levels and P fertilizer significantly affected total phosphorus uptake and PHI in the combined analysis, as shown in Fig. 3. Under various HA levels, the highest total P uptake was recorded for faba bean plants fertilized with 37.5 kg P_2O_5/Fad.. This trend aligns with findings by **Fouda (2017), Awaad *et al.* (2020),** and **Al-Azze *et al.* (2023)**. Interestingly, faba bean plants treated with 3 kg HA/Fad. without additional P fertilizer (control treatment) recorded the highest PHI values, demonstrating the potential efficiency of HA in enhancing phosphorus utilization even in the absence of supplementary P applications.

Phosphorus Uptake Efficiency (PUPE), Phosphorus Utilization Efficiency (PUZE), and Phosphorus Use Efficiency (PUE)

Effect of humic acid (HA)

The results indicated that HA levels significantly influenced PUPE, PUZE, and PUE. In both seasons and combined analysis, PUPE increased significantly as HA levels increased from 0 to 3 and then to 6 kg/Fad. (Table 6). Similarly, PUE increased significantly with HA application, particularly up to 3 kg/Fad., with the first season showing a cosiderable response. This improvement in phosphorus efficiency is consistent with findings from **El-Etr *et al.* (2011)** and **Awaad *et al.* (2020)**, who reported that HA enhanced P availability and uptake by solubilizing phosphorus from insoluble to soluble forms (**Sherif and Ali, 2018**). However, PUZE decreased as HA levels increased from 0 or 3 to 6 kg/Fad. in both seasons and from 0 to 3 and then to 6 kg/Fad. in the combined analysis. This trend suggests that while HA application increase phosphorus availability and uptake, it may lower PUZE. Increased soil phosphorus availability often results in higher P uptake, but this can reduce PUZE, as noted by **Daoui *et al.* (2012)**, due to a dilution effect where excess P availability does not proportionally translate to increased yield.

Effect of phosphorus (P) fertilizer levels

Results from both seasons and combined analysis implied that increasing P levels significantly reduced PUPE, PUZE, and PUE (Table 6). Although phosphorus application is essential for plant growth, these findings align with **Daoui *et al.* (2012),** who reported a reduction in phosphorus uptake efficiency with higher P levels. Similarly, studies by **Daoui *et al.* (2012)** and **Papakaloudis and Dordas (2023)** observed a significant reduction in PUE with increased P application, suggesting that excessive P availability does not necessarily translate into enhanced phosphorus utilization efficiency. **Nebiyu *et al.* (2016)** reported no significant effect of P fertilizer on PUZE, highlighting the variable responses of different efficiency to P levels. Furthermore, the observed negative relationship between PUZE or PUE with biological yield supported the idea that high P application may shift the plant focus to vegetative growth rather than reproductive yield. This shift reduces competition between vegetative and reproductive growth, allowing for an increase in PUZE and PUE (**Daoui *et al.*, 2012**).

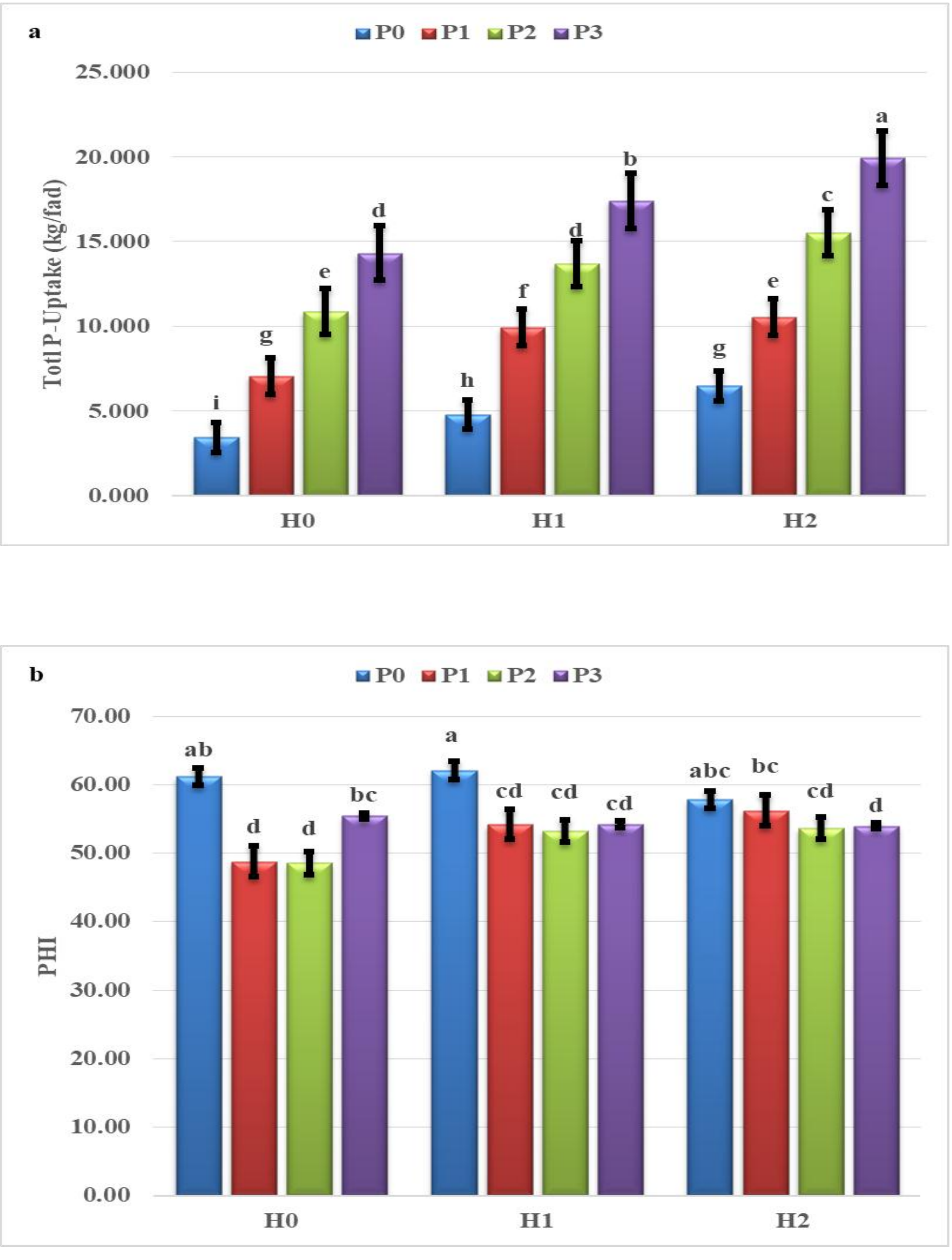

Fig. 3. Interaction effects of humic acid (HA) levels and phosphorus (P) fertilizer level (combined data) on (a) total P uptake and (b) Phosphorus harvest index (PHI). Error bars on the columns represent the standard error (SE), and treatments characterized with the same letter are not significantly different at $p < 0.05$. H0: control, H1: 3 kg HA/Fad., H2: 6 kg HA/Fad., P0: control, P1: 12.5 kg P_2O_5/Fad., P2: 25 kg P_2O_5/Fad., and P3: 37.5 kg P_2O_5/ Fad.

Table 6. Effects of humic acid levels, phosphorus fertilizer levels, and their interaction on phosphorus uptake efficiency (PUPE), phosphorus utilization efficiency (PUZE), and phosphorus use efficiency (PUE) in faba bean for the 2020/2021 and 2021/2022 seasons, and combined analysis.

Studied factors	PUPE (kg P absorbed/kg P available			PUZE (kg seed/kg P absorbed)			PUE (kg seed/kg P available)		
	1st Season	2nd Season	Comb.	1st Season	2nd Season	Comb.	1st Season	2nd Season	Comb.
Humic acid level (H)									
Control (H0)	0.239 c	0.392 c	0.316 c	252.82 a	217.86 a	235.34 a	62.97 c	86.20 b	74.59 b
3 kg/Fad. (H1)	0.355 b	0.474 b	0.415 b	239.28 a	202.08 a	220.68 b	90.85 b	98.17 ab	94.51 a
6 kg/Fad. (H2)	0.446 a	0.557 a	0.501 a	205.38 b	175.45 b	190.41 c	99.48 a	100.22 a	99.85 a
F-test	**	**	**	**	*	**	**	*	**
Phosphorus fertilizer level (P)									
Control (P0)	0.479 a	0.525 a	0.502 a	380.53 a	319.84 a	350.19 a	170.49 a	162.91 a	166.70 a
12.5 kg P_2O_5/Fad. (P1)	0.322 b	0.475 b	0.398 b	232.17 b	198.11 b	215.14 b	74.65 b	93.54 b	84.10 b
25 kg P_2O_5/Fad. (P2)	0.308 b	0.453 c	0.381 c	167.98 c	150.68 c	159.33 c	51.48 c	67.90 c	59.69 c
37.5 kg P_2O_5/Fad. (P3)	0.278 c	0.445 c	0.361 d	149.30 c	125.21 d	137.25 d	41.12 d	55.11 d	48.11 d
F-test	**	**	**	**	**	**	**	**	**
Interaction:									
H×P	**	*	**	**	**	**	**	NS.	**

*, and ** signify significance at the 0.05 and 0.01 levels, respectively, while NS indicates non-significanc

Interaction effects

The interaction between HA and P exhibited a significant effect on PUPE, PUZE, and PUE, as shown in Fig. 4. At all HA levels, unfertilized faba bean plants with phosphorus exhibited higher values of PUPE, PUZE, and PUE compared to those treated with phosphorus. The highest PUPE was achieved with 6 kg HA/Fad. without P fertilizer application, while the highest PUE was achieved with 3 or 6 kg HA/Fad. without additional phosphorus. On the other hand, the highest PUZE was obtained without humic or P application. These results can be attributed to the ability of HA to form complexes with soluble phosphorus, enhancing its availability in the soil (**Farid *et al.*, 2021**). This interaction suggests that HA may improve phosphorus efficiency independently of phosphorus fertilization, potentially reducing the need for high phosphorus inputs by increasing phosphorus availability in a more sustainable manner.

Conclusion

This study concluded that the application of 3 kg HA/Fad. combined with 37.5 kg P_2O_5/Fad. under drip irrigation in sandy soil conditions produced the highest seed yield per Fad. and harvest index (HI). Notably, the highest phosphorus use efficiency (PUE) was achieved with 3 kg HA/Fad. in the absence of additional phosphorus fertilization. These results suggest that HA application can enhance soil fertility and increase phosphorus availability, potentially reducing the need for high phosphate fertilizer applications and thereby minimizing environmental pollution. Integrating HA into nutrient management strategies offers a promising approach to improving crop yield and sustainability in nutrient-poor sandy soils.

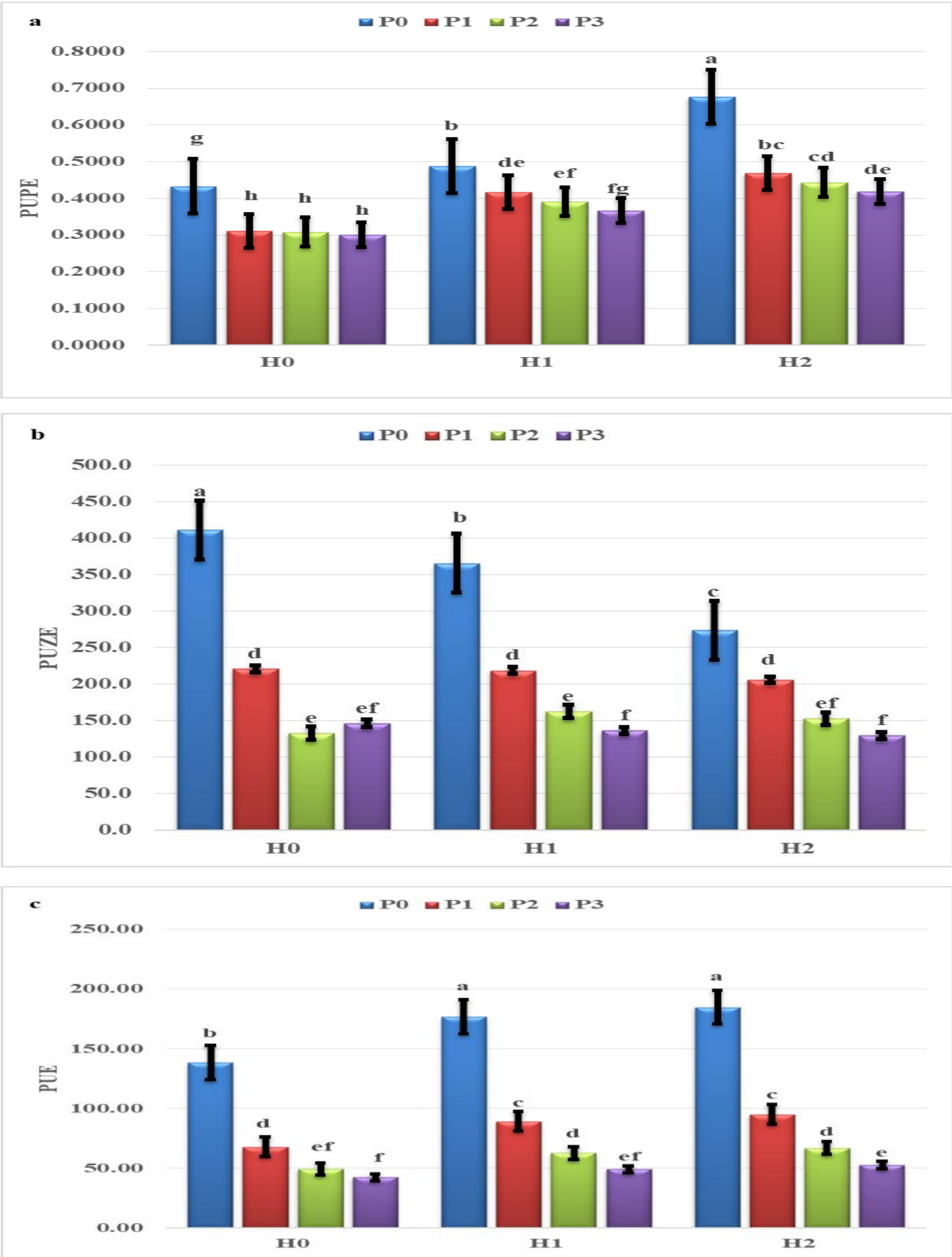

Fig. 4. Interaction effect between humic acid (HA) levels and phosphorus fertilizer (P) level (combined data) on PUPE (a), PUZE (b) and PUE (c). Error bars on the columns represent the standard error (SE), and treatments characterized with the same letter are not significantly different at $p < 0.05$. H0: control, H1: 3 kg HA/Fad., H2: 6 kg HA/Fad., P0: control, P1: 12.5 kg P_2O_5/Fad., P2: 25 kg P_2O_5/Fad., and P3: 37.5 kg P_2O_5/Fad.

REFERENCES

Afifi, M.H.M., M.F. Mohamed and S.H.A. Shaaban (2010). Yield and nutrient uptake of some faba bean varieties grown in newly cultivated soil as affected by foliar application of humic acid. J. Plant Prod., 1 (1): 77-85.

Akinci, S., T. Buyukkeskin, A. Eroglu and B.E. Erdogan (2009). The effect of humic acid on nutrient composition in broad bean (*Vicia faba* L.) roots. Not. Sci. Biol. J., 1(1): 81-87.

Al-Azze, A.J.A., A.H. Raheem and K.S.A. Al-Obaidy (2023). Broad bean (*Vicia faba* L.) crop growth and yield response to humic acid and phosphorus fertilizer. Nativa, Sinop, 11 (3): 408-421.

Al-Shareef, A.R., F.S. Nakhlawy and S.M. Ismail (2018). Enhanced mungbean and water productivity under full irrigation and stress using humic acid in arid regions. Legum. Res. Int. J., 41(3):428–431.

Awaad, M.S., M.A. El-Shazly and T.H. M.A. Deshesh (2020). Effect of potassium humate and phosphorus fertilization on faba bean plants of yield and its content of nutrients. Menoufia J. Soil Sci., 5(7): 161-171.

Baccari, B., H. Ellouzi and A. Krouma (2024). Genotypic differences in the physiological response of faba bean (*Vicia faba* L.) to phosphorus deficiency. Russian Journal of Plant Physiology 71(77):1-10.

Canellas, L. P., F. L. Olivares, N. O. Aguiar, D. L. Jones, A. Nebbioso, P. Mazzei and A. Piccolo (2015). Humic and fulvic acids as biostimulants in horticulture. Sci. Hort., 196: 15 –27.

Daoui, K., M. Karrou, R. Mraber, Z. Fatemi, X. Draye and J.F. Ledent (2012). Genotypic variation of phosphorus use efficiency among moroccan faba bean varieties (*Vicia faba* major) under rainfed conditions. J. Plant Nutr., 35: 34-48.

Duncan, D.B. (1955). Multiple Ranges and Multiple "F" test. Biometrics, 11: 1-42.

El-Etr, W.T., M.A. Osman and A.A. Mahmoud (2011). Improving phosphorus use effeciency and its effect on the productivity of some crops. J. Soil Sci. and Agric. Eng., Mansoura Univ., 2 (9): 1019-1034.

El-Guibali, A. H., Attia, M. A. and S. E. Omran (2016). Potassium fertilization in conjuction with foliar applied molybdenum and humic substances for faba bean. J. Soil Sci. and Agric. Eng., Mansoura Univ. 7(7): 501-507.

El-Kholy, A.S.M., R.M.A. Aly, A.Y.A. El-Bana and M.A.T. Yasin (2019). Yield of faba bean (*Vicia faba*, L.) as influenced by planting density, humic acid rate and phosohorus fertilization level under drip irrigation system in sandy soils. Zagazig J. Agric. Res., 46 (6A): 1785-1795.

El-Safy, A.E., S.A.H. Allam, E.M.M. El-Gedawy and F. T. Z. El-Sheikh (2021). Performance of some faba bean varieties in relation to phosphorus fertilization and some microelements spraying. Annals of Agric. Sci., Moshtohor, 59(2): 383-398.

El-Sobky, E.E.A. and M.A.T. Yasin (2017). Phosphorus and micronutrients fertilization impact on faba bean productivity (*Vicia faba* L.). Zagazig J. Agric. Res., 44 (3): 853-863.

FAOSTAT (2022). Statistical Databases and Data Sets of the Food and Agriculture Organization of the United Nations. Available online: http:// www.fao.org/ faostat/en/# data.

Farid, I. M., M. A. El-Ghozoli, M. H. H. Abbas, D. S. El-Atrony, H.H. Abbas, M. Elsadek, H. A. Saad, N. El Nahhas and I. Mohamed (2021). Organic materials and their chemically extracted humic and fulvic acids as potential soil amendments for faba bean cultivation in soils with varying $CaCO_3$ contents. Hort., 7(205):1-13.

Fathy, N., T. A. Tewfike, H. M. Abdel-Rahman and R. A. Zaghloul (2023). Alleviation of drought stress in faba bean using humic acid and inoculation with plant growth promoting rhizobacteria. Annals of Agric. Sci., Moshtohor, 61 (1): 219-230.

Fouda, K.F. (2017). Effect of phosphorus level and some growth regulators on productivity of faba bean (*Vicia faba* L.). Egypt. J. Soil Sci., 57 (1): 73-87.

Gomez, K.N. and A.A. Gomez (1984). Statistical Procedures for Agriculture Research. John Wiley and Sons, New York, 2nd Ed.

Hosseinzadeh, H. (2005). Report of effect Barvare 2 biofertilizer on yield grain legume. Tehran Jehad. Daneshgahi and Fannavari Sabz.Co.Press. p. 25.

Kasem, F.E.A. (2012). Studies on fertilizer requirements of faba bean. M. Sc. Thesis, Fac. Agric, Cairo Univ, Egypt.

Kubure, T.E., C.V. Raghavaiah and I. Hamza (2016). Production potential of faba bean (*Vicia faba* L.) genotypes in relation to plant densities and phosphorus nutrition on vertisols of central highlands of west showa zone, ethiopia, east africa. Adv. Crop Sci. Tec., 4 (2): 1-9.

Lal, M., A.K. Pal, M.C. Agrawal, K.U. Rani and D.S. Chandrika (2016). Effect of phosphorus and molybdenum on yield and nutrient uptake of faba bean in alluvial soil. Annals of Plant and Soil Res., 18(3): 262-265.

Li, Jun., L. Yuan, B. Zhao, Y. Li, Y. Wen, W. Li and Z. Lin (2017). Effect of adding humic acid to phosphorous fertilizer on maize yield and phosphorus uptake and soil available phosphorus content. J. Plant Nutr. and Fertilizer, 23(3): 641-648.

Moll, R. H., E. J. Kamprath, and W. A. Jackson. (1982). Analysis and interpretation of factors which contribute to efficiency of nitrogen utilization. Agron. J., 74: 562–564.

Nebiyu, A., A. Vandorpe, J. Diels and P. Boecky (2014). Nitrogen and phosphorus benefits from faba bean (*Vicia faba* L.) residues to subsequent wheat crop in the humid highlands of Ethiopia. Nutr. Cycl. Agro. Eco. Sys., 98: 253-266.

Nebiyu, A., J. Diels and P. Boecky (2016). Phosphorus use efficiency of improved faba bean (*Vicia faba*) varieties in low-input agro-ecosystems. J. Plant Nutr. Soil Sci., 179: 347 -354.

Oukaltouma, K., A. El Moukhtari, Y. Lahyizi, M. Mouradi, M. Farissi, A. Willems, A. Qaddoury, F. Bekkaoui and C. Ghoulam (2021). Phosphorus deficiency enhances water deficit impact on some morphological and physiological traits in four faba bean (*Vicia faba* L.) varieties. Italian J. Agron., 16 (1)1662-1675.

Page, A.L., R.H. Miler and D.R. Keeney (1982). Methods of Soil Analysis" , Part2. Chemical and Microbiological Properties. Agron. Monographs No. 9, 2nd Ed., 539-624.

Papakaloudis, P. and C. Dordas (2023). Phosphorus fertilization affects morphological, physiological and agronomic characteristics of faba bean cultivars. Sustainability 15. 13172:1-24.

Rose, T.J. and M. Wissuwa (2012): Rethinking internal phosphorus utilization efficiency: A new approach is needed to improve PUE in grain crops. Adv. Agron., 116: 185–217.

Roudgarnejad, S., M. Samdeliri, A. M. Mirkalaei and M. N. Moghaddam (2021). The role of humic acid application on quantitative and qualitative traits of faba bean (*Vicia faba* L.). Gesunde Pflanzen, 73: 603-611

Ryan, J., G. Estefan and A. Rashid (2001). Soil and Plant Analysis Laboratory Manual. International Center for Agricultural Research in the Dry Areas (ICARDA), National Agricultural Research Center (NARC), Aleppo, Syria.

Sherif, M. I. and M.A. Ali (2018). Effect of potassium humate application on yield and nutrient uptake of maize grown In a calcareous Soil. Alexandria Science Exchange J., 39 (3): 412-418.

Steel, R.G.D., J.H. Torrie and D.A. Dicky (1997). Principles and Procedures of Statistics, a Biological Approach. 3rd Ed. MacGraw Hill Book Co. New York.

Stern, R. (1991). Review of Co-Stat-Statistical Software. Exp. Agric., 27(1):87.

Taha, S. S., and A. Sh. Osman (2017). Influence of potassium humate on biochemical and agronomic attributes of bean plants grown on saline soil. J. Hort. Sci. and Biotechnol., 93 (5): 545-554.

Yousif, S.H., K.H. Yousif and S.M. Salih (2019). Effect of bread yeast and humic acid on growth and yield traits on broad bean (*Vicia faba* L.). J. Univ. Duhok Agric. and Vet. Sci., 22(1): 98-106.

تأثير حمض الهيوميك ومستويات الفوسفور على المحصول وكفاءة إستخدام الفوسفور فى الفول البلدى المنزرع تحت ظروف الأراضى الرملية

أحمد سليمان محمد الخولى – إيمان عبدالله محمد

قسم المحاصيل - كلية الزراعة - جامعة الزقازيق – مصر

يعتبر الإستخدام الكفء للفوسفور أمر بالغ الأهمية فى إنتاج الفول البلدى للزراعة المستدامة خاصة فى الأراضى الرملية ذات المحتوى المنخفض من العناصر الغذائية الميسرة للنبات. تهدف هذه الدراسة إلى تقييم تأثير مستويات مختلفة من حمض الهيوميك والسماد الفوسفاتى على كفاءة إستخدام الفوسفور وإنتاجية الفول البلدى تحت ظروف الأراضى الرملية. أجريت تجربة حقلية فى الموسمين الشتويين 2021/2020 و 2022/2021 فى المزراعة التجريبية لكلية الزراعة جامعة الزقازيق بمنطقة الخطارة - محافظة الشرقية – جمهورية مصر العربية. تمت معاملة نباتات الفول البلدى بثلاث مستويات إضافة أرضية من حمض الهيوميك: كنترول (بدون إضافة) و 3كجم للفدان و 6 كجم للفدان، وأربع مستويات من الفوسفور كنترول (بدون إضافة) و 12.5 كجم بو$_2$أ$_5$ للفدان و 25 كجم بو$_2$أ$_5$ للفدان و 37.5 كجم بو$_2$أ$_5$ للفدان. حقق إضافة حمض الهيوميك بمعدل 6 كجم للفدان أعلى القيم لصفات عدد القرون والبذور للنبات ووزن بذور النبات ووزن الـ 100 بذرة والفوسفور الكلى الممتص وكفاءة امتصاص الفوسفور. تشير نتائج التحليل المشترك لموسمى الزراعة إلى أن إضافة حمض الهيوميك بمعدل 3 كجم للفدان أدى إلى زيادة معنوية فى صفات محصول البذور للفدان ودليل الحصاد وكفاءة استخدام الفوسفور، إلا أن كفاءة استعمال الفوسفور إنخفضت معنويا بإضافة حمض الهيوميك، فى حين لم يتأثر دليل حصاد الفوسفور بإضافة حمض الهيوميك. وأدى إضافة الفوسفور بمعدل 37.5 كجم بو$_2$أ$_5$ للفدان الى زيادة معنوية فى صفات عدد القرون والبذور للنبات ووزن بذور النبات ووزن الـ 100 بذرة ومحصول البذور والمحصول البيولوجى للفدان ودليل الحصاد حصاد الفوسفور وكفاءة امتصاص الفوسفور وكفاءة الاستفادة من الفوسفور وكفاءة استخدام الفوسفور.

المحكمـــون:

1- أ.د. المتولى عبدالله المتولى أستاذ المحاصيل – كلية الزراعة – جامعة القاهرة.

2- أ.د. محمد عبدالسلام طـــه أستاذ المحاصيل – كلية الزراعة – جامعة الزقازيق.