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Response of Green Faba Bean Yield: As Nexus of Water Deficit, P-Fertilizers, and Phosphorus Recovery

Mohamed E. A. Aboukota (Corresponding Author)
Soils, Water and Environmental Research Institute- Agricultural Research Center (ARC)
Email: aboukota.m@gmail.com

Hossam A. Sallam
Horticulture Research Institute - Agricultural Research Center (ARC)

Mohamed A. M. Eid
Soils, Water and Environmental Research Institute- Agricultural Research Center (ARC)

Mona H. M. Kenaw
Soils, Water and Environmental Research Institute- Agricultural Research Center (ARC)

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Abstract

Water and fertilizer optimum management in agriculture is important in improving crop productivity, two field experiments were conducted in El-Qanater Horticultural Research Station, Qalubiya Governorate, Egypt, during 2022/2023 and 2023/2024 to study the response of (Vicia faba L.,) Giza 716 faba bean cultivar to three irrigation water levels 100 % of potential evapotranspiration, ET crop (I_1), 80 % ET crop (I_2) and 60 % ET crop (I_3) of irrigation requirements, the effect of applying P-fertilizers no P-fertilization (P_0); powdered calcium super phosphate (P1); granular calcium superphosphate (P_2) and powdered rock phosphate (P_3) all P-sources inoculated by *B. megaterium*. The obtained results could be summarized as follows: Increasing the applied amount of irrigation water from 3172 (I_3) to 4229 m^3 ha^{-1} (I_2) and (P_3) gave the highest values of all growth characters, except plant height and amount of pods/ plant in average values of both seasons. Moreover, the 80% ET crop (I_2) and rock phosphate sources treatment increased yield values attributes, and NPK contents of seeds. Also, the highest values of Irrigation Water productivity (IWP) kg m^{-3} faba bean green pods and seed quality (protein %) occurred with 80% ET crop (I_2) of irrigation water level and powdered rock phosphate (P_3).

Keywords: Faba bean; Water deficit; P-Fertilizers; Phosphorus recovery.

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1. Introduction

The agricultural sector consumes about 80-90% of Egypt's total water share; hence, optimal water use in crops has become a national issue. Innovative irrigation practices such as wide irrigation intervals, high soil moisture depletion, skipping irrigation at growth stages not affected by soil moisture deficiency, etc., can reduce crop irrigation requirements. In Egypt, faba (Vicia faba L.) is a major winter legume crop rich in proteins and carbohydrates [1]. Many studies have required analysis of drought stress from plant physiological and biochemical characteristics. Therefore, studies have been directed toward enhancing efficient fertilization to increase biomass production even under water shortage [2, 3].

Phosphorus (P) is widely present and abundant in soils, but they suffer from a deficiency of available phosphorus even if these soils are continuously fertilized with soluble phosphorus, this is due to the rapid conversion of soluble phosphate to insoluble phosphate (such as $Ca_3(PO_4)_2$ in alkaline and calcareous soils or Fe or Al in acidic soils [4]. Studies have shown that the yield and its components of faba bean (plant height, number of branches per plant, number of pods per plant) decreased significantly with decreasing number of seeds per pod, pod weight, 100-seed weight, and seed yield per acre decreased substantially with lowing number of irrigations, yield decreased by 52 and 15.5% with two irrigations, respectively, compared to three irrigations. This decrease in yield may be due to the small number of branches, and taking into the record the number of pods and seeds per plant, pod weight, and 100-seed weight, it appears that 4 irrigations after planting are optimal for obtaining a high yield of faba bean seeds [5, 6]. Applied studies have focused on the use of P-solvent bacteria. Production is linked to its use as a vector in recombinant protein production. However, *B. megaterium* is known for its abundance in soil, colonization of many plants, and support of plant growth, it also contributes to plant growth promotion [7, 8]. Soil *B. megaterium* bacteria enhance the following: 1) Enhance the secretion of plant hormones (phytohormone), including indole acetic acid, which increases root growth and root hair length, thus increasing water absorption. 2) Produce organic acids, which are a source of protons (H^+), thus reducing acidity and alkalinity in the soil, increasing phosphorus solubility, organic acids act as a chelating compound (chelates calcium, releasing phosphorus), and the forms of organic acids (citric acid and gluconic acid). 3) Secrete the alkene phosphatase enzyme, which breaks the ester phosphate bond, thus releasing phosphorus and increasing its release into the soil [9, 10]. Hence, the present study investigated to the effect of applying P-fertilizers and *B. megaterium* under different irrigation levels.

2. Materials and Methods

A field experiment was done at El-Qanater Horticultural Research Station, Middle Nile Delta, Qalubiya Governorate, Egypt. It sprawls between the Latitude: 30°08' N, Longitude: 31°15' E, Elevation: 16.9 m ASL) over two successive winter seasons of 2022/2023 and 2023/2024 on Faba bean "*Vicia Faba*" cv Giza 716 irrigated with Nile water. The sowing date was on 9 & 12 of October for both seasons. The design of the experiments was factorial, split-plot with irrigation being the main plots and P-fertilizer sources as sub-plots in 3 replicates each plot area was 12 m^2, and the soil texture was clay loam. Soil Physio-chemical properties are illustrated in Table 1, Soil moisture content was gravimetrically determined in soil samples taken from consecutive depths of 15 cm down to a depth of 60 cm. For irrigation timing, soil samples were collected before each irrigation, 48 hours after, and at harvest time, to estimate water consumptive use [11]. Field capacity, permanent wilting point, and bulk density were determined by Klute [12], and are given in Table 2. Table 3 shows the meteorological data in the district, during the two seasons of the research. All plots received N 48 kg ha^{-1} ordinary NH_4NO_3, (33.5% N) dose refresher, K as K_2SO_4 (48% K_2O) 120 kg ha^{-1}, and the combination of biofertilization. N, K, and biofertilization with *B. megaterium* were each applied in one dose during soil preparation before planting.

Table-1. Average values of some particle size distribution and soil chemical properties for the studied area.

Parameter		**Value**
Texture (International Texture Classification) Clay loam	Clay	31.4
	Silt	33.5
	Fine sand	34
	Coarse sand	1.1
$CaCO_3$ (g kg^{-1})		0.8
Organic matter (g kg^{-1})		9
Available N (mg kg^{-1}) (KCl extract)		81
Available K (mg kg^{-1}) (AB-DTPA extract)		238.9
Available P (mg kg^{-1}) (AB-DTPA extract)		9.33
pH (1: 2.5 w/v soil: water suspension)		7.49
EC dS m^{-1} (paste extract)		1.1
Saturation %		67.5
Cations and anions in soil paste extract (mmol$_c$ L^{-1})	Na^+	4.1
	K^+	0.41
	Ca^{2+}	3.07
	Mg^{2+}	2.63
	CO_3^{2-}	0.0
	HCO_3^-	3.85
	Cl^-	3.7
	SO_4^{2-}	2.66

Table-2. status of Field capacity wilting point, available water, and bulk density of the soil profile for the studied area.

Depths	**Field capacity FC (% w/w)***	**Wilting point WP (% w/w)***	**Available water AW (% w/w)***	**Bulk density BD (g./cm^3)***
0-15	37.9	18.1	19.8	1.27
15-30	36.1	17.6	18.5	1.30
30-45	33.5	16.9	16.6	1.31
45-60	32.5	16.2	16.3	1.34

Table-3. Some Agro-meteorological data for the studied experimental site in seasons 2022/2023 and 2023/2024.

Season	**2022/2023**							**2023/2024**						
Month	**T. max**	**T. min.**	**W.S**	**R.H**	**S.S**	**S.R**	**R.F**	**T. max**	**T. min.**	**W.S**	**R.H**	**S.S**	**S.R**	**R.F**
October	31.5	17.7	3.0	54.7	9.3	18.3	1.3	32.0	19.4	2.6	58.1	8.6	17.4	53.0
November	27.5	14.9	2.3	62.6	8.0	14.0	20.1	26.7	14.9	2.4	65.1	7.8	13.8	5.3
December	19.5	9.0	2.6	68.3	6.1	10.9	30.3	22.5	11.5	2.4	71.7	6.5	11.3	26.0
January	16.8	5.4	2.5	67.1	6.7	12.1	33.2	20.4	8.3	2.2	59.2	6.7	12.1	4.4
February	19.5	6.6	2.5	66.6	7.7	15.5	10.6	21.3	8.2	2.4	61.3	7.3	15.0	7.6

Where: T. max., T. min. = maximum and minimum temperatures °C; W.S.= wind speed (m/see); R.H. = relative humidity (%); S.S. = actual sun shine (hour); S.R. = solar radiation (cal/cm^2/day). RF = rainfall (mm/month).

2.1. Factors of the Experiment are 2 as Follows

2.1.1. Main Plots (Irrigation Treatments)

Three amounts of applied irrigation water based on the Penman-Monteith equation were tested in this experiment. The irrigation treatments were as follows:

- I_1; Irrigation with an amount of water equals 100% of potential evapotranspiration (ET crop)

- I_2; Irrigation with amount of water equals 80% of potential evapotranspiration ET crop.
- I_3; Irrigation with amount of water equals 60% of potential evapotranspiration ET crop.

2.1.2. Subplots (Phosphorus fertilizer Sources, P)

- P_0: no P-fertilization;
- P_1: powdered calcium super phosphate (PSP);
- P_2: granular calcium superphosphate (GSP) and
- P_3: powdered rock phosphate (RP);
- The analysis of P-fertilization has been listed in (Table, 4).
- **Notification**: Rate of P = 48 kg P ha^{-1} before seeding.

Table-4. The analysis results of Ca-superphosphate (CSP), and rock phosphate (RP) used in the studied experimental

Source	Total P (g kg^{-1})	Available P (g kg^{-1})	Contents of total micronutrients (mg kg^{-1})			
			Fe	**Mn**	**Zn**	**Cu**
Ca-superphosphate (**CSP**)	69	69	28	255	182	3
granular calcium superphosphate (GSP)	68	68	28	253	180	3
rock phosphate (**RP**)	130	-	4100	149	796	12

2.2. Crop-Soil-Water Relation

2.2.1. Reference Evapotranspiration (ETo

ETo values were calculated based on local agro-meteorological data of the experimental site (Table 3) according to the Penman-Monteith equation FAO [13]. Calculations were performed using the CROPWAT model FAO [14]. The Eto values (in mm day-1) were calculated on average for two seasons as 4.3, 3.7, 3.2, 3.4, and 3.9 for October, November, December, January, and February, respectively.

2.2.2. Crop Evapotranspiration (ET_C)

The ETc values were calculated according to the following equation given by FAO [15] Allen, *et al.* [16]**:**

ETc = ETo × Kc

Where:

ET_c: crop evapotranspiration (mm day^{-1})

ET_o: reference crop evapotranspiration (mm day^{-1})

K_c: crop coefficient.

The crop coefficient values applied were 0.47, 0.63, 0.73, 0.84, and 0.97 for October, November, December, January, and February, respectively (FAO 56).

2.2.3. Amount of Applied Irrigation Water (AIW)

The amounts of applied irrigation water were calculated according to the equation given by Vermeiren and Jopling [17]:

$$AIW = \frac{ETc \rightarrow\!| \; I}{Ea\,(1 - LR)}$$

Where:

AIW: depth of applied irrigation water (mm)

Etc: crop evapotranspiration (mm day^{-1}).

Kr: The reduction factor depends on the land cover

I: irrigation interval (days)

Ea: irrigation application efficiency for the drip irrigation system (≈ 90% at the site location).

LR: leaching requirements: the extra amount of applied water needed for salt leaching, calculated according to FAO [18] as follows:

$$LR = \frac{ECiw}{ECe}$$

Where:

ECiw: salinity of irrigation water (dS m^{-1}) and ECe: average soil salinity tolerated by the crop as measured by soil saturated extract (dS m^{-1}). Under the current experimental conditions, no additional water was added for leaching to avoid any effect on stress treatments.

Table-5. Average Crop evapotranspiration (ET_C) for 2022/2023 and 2023/2024 seasons for the studied area

Season / Month	(ETc)		
	Kc	2022/2023 and 2023/2024	
		mm/day	mm/month
October	0.47	2.02	40.33
November	0.63	2.34	70.21
December	0.73	2.37	73.32
January	0.84	2.89	89.45
February	0.97	3.75	67.57
Seasonal (mm)		13.36	340.88

2.2.4. Irrigation Water Applied (IWA)

The water amount applied in each plot of siphon tubes was calculated from the following equation [19].

$Q = Ca.\ A\sqrt{2gh}$

Where:

Q = the quantity of water applied in $m^3\ s^{-1}$

Ca = coefficient of discharge (0.61)

A = ($\pi\ d^2$ /4) where π = equal to 3.14

d^2 = inside radius square for the siphon tube 2

g = the gravity equal to 9.81 m. s^{-2}

h = the head of water in the main irrigation canal in m.

Irrigation application efficiency was 65%

2.2.5. Irrigation Water Productivity (IWP)

Applied irrigation water describes the relationship between production and the amount of water applied. It was determined according to Zhang [20] The following equation was used as follow:

$$IWP = \frac{\text{Green Yield (kg ha}^{-1})}{\text{Total seasonal applied water (m}^3\text{ha}^{-1})}$$

2.3. Measured Parameters

2.3.1. Crop Parameters

Samples of ten plants were taken from each plot picked randomly at harvest and the following data were recorded: Plant height, number of leaves plant^{-1}, number of branches plant$^{-1,}$ Yield and yield components (number of pods plant^{-1}, weight of green pods, g plant^{-1}, NPK-uptake and protein percent.

2.3.2. Laboratory Analyses of Plant and Soil Materials

Particle size analysis is determined by the pipette method Piper [21]. Other analyses for plant, soil, and water materials were determined by methods cited by Chapman and Pratt [22], Klute [12], Page, *et al.* [23]. Sulfate ions in water and soil paste extract were computed by subtraction.

2.3.3. Recovery of Applied Phosphorus (PR)

% was calculated as follows:

*P recovery (%) = (P PDF / P applied) * 100* Whereas, P PDF: the amount of plant uptake. P applied: amount of P applied **(Franzini et al., 2009).**

2.3.4. Statically Analysis

All the obtained results during the two seasons of their study were subjected to the statistical analysis of variance method according to Snedecor and Cochran [24]. However, the mean values of each investigated factor (specific effect) and their combination (interaction effect) of four studied parameters were compared according to Duncan's multiple range test [25, 26]. Capital letters were used for distinguishing means within each column or row representing the specific effect of any investigated factor (NEC) applied rate and (EM) soil added contrast, the small letters were employed for the interaction effect of their combination.

3. Results and Discussion

3.1. Crop-Water Relation

3.1.1. Applied Irrigation Water (AIW)

Results in Table 6 show that seasonal irrigation water applied to the P-fertilizer Faba bean plants were 5286, 4229, and 3172 $m^3\ ha^{-1}$ for I_1, $I_{2,}$ and I_3 (i.e. 100, 80, and 60% of ETc), respectively. The observed increase in the period from October to February highlights the development of the growth stage from the formation stage during October to the vegetative stage during November. It also increases during flowering and pod formation in December, increases during pod formation and bean filling in January, and decreases during maturity in February. The results are consistent with those reported by Mansouri, *et al.* [27].

Table-6. Average monthly and seasonal applied irrigation water ($m^3 ha^{-1}$) for the Faba bean experiment for the 2022/2023 and 2023/2024 seasons.

Average monthly and seasonal applied irrigation water (m^3 ha^{-1}) for the faba bean experiment for the 2022/2023 and 2023/2024 seasons	Month	I_1=ETc 100 %		I_2 = ETc 80 %		I_3 = ETc 60 %	
	October	31.27	625	25.01	500	18.76	375
	November	36.29	1089	29.04	871	21.78	653
	December	36.68	1137	29.34	910	22.01	682
	January	44.75	1387	35.80	1110	26.85	832
	February	58.21	1048	46.57	838	34.93	629
	Seasonal (m^3 ha^{-1})	207	5286	166	4229	18.76	3172

3.1.2. Irrigation water productivity (IWP, kg m^{-3})

Results in Table 7 and Figure 1 show that the lowest faba bean green pods yield of 4.27 kg m^{-3} was obtained by the non-fertilized treatments under the P_0 I_1 irrigation regime for both seasons. The highest green bean pod productivity of 9.66 kg m^3 was obtained with P_3 fertilized treatments under irrigation system I_2: ETc 80% for both seasons. The values of IWP were in the range of 4.27 and 9.66 kg m^{-3} and are close to values reported by Papakaloudis and Dordas [28].

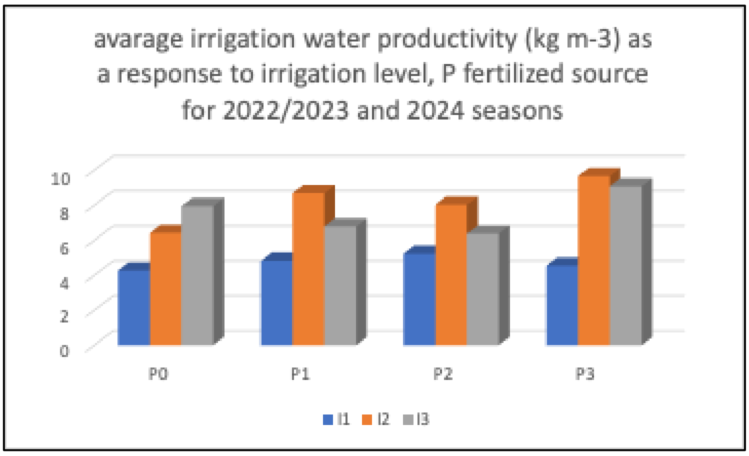
Irrigation effect: Results in Table 7 and Figure (1) show that the main impact of the irrigation regime shows that I_2> I_3> I_1 with average increases of 9.8 and 74.3% for I_2 over I_3> I_1, for two seasons, respectively. The greater IWP by the I_2 treatment was particularly obtained under conditions of the P_3: Rock phosphate. The current results supported those obtained by Berhanu [29]. The current results disagree with those obtained by Awadalla, *et al.* [30] who mentioned that the highest value irrigation water productivity was obtained by 60% ETc. The current results disagree with those obtained by Fayed, *et al.* [31] who recorded that the 0.60 irrigation level gave the highest water use efficiency value. The current results supported those obtained by Chtouki, *et al.* [32] who demonstrated that the IWP was significantly increased under moderate (I_2) and severe water stress (I_3), compared to the full irrigation regime (I_1).

fertilizer source effect: Results in Table 7 and Figure (1) show that the main impact of the P-fertilizer source shows that $P_3 > P_1 > P_2 > P_0$ with average increases of 14.4, 18.7 and 25.2% for P_3 over $P_1 > P_2 > P_0$ for two seasons, respectively. The greater IWP by the P_3 treatment was particularly obtained under the I_2: ETc 80% conditions.

Table-7. Average irrigation water productivity (kg m^{-3}) as a response to irrigation level, and P-fertilized source for 2022/2023 and 2023/2024 seasons.

Irrigation treatments		Irrigation Water productivity (IWP) kgm^{-3} faba bean green pods				
		P-fertilizer sources				
		P_0	P_1	P_2	P_3	Mean
I_1		4.27 i	4.83 h	5.23 g	4.55 i	4.72 C
I_2		6.42 f	8.69 c	8.03 d	9.66 a	8.20 A
I_3		7.95 d	6.79 e	6.38 f	9.08 b	7.55 B
Mean		6.21 D	6.77 B	6.55 C	7.76 A	
LSD at 5%	A	0.079				
	B	0.091				
	AB	0.157				

Figure-1. Average irrigation water productivity (kg m^{-3}) as a response to irrigation level, and P-fertilized source for 2022/2023 and 2023/2024 seasons



3.2. Plant Height (cm)

Results in Table 8 and Figure 2 show that the lowest faba bean Plant height (cm) of 102 cm was obtained by the treatments of P_2 I_2 Granular calcium superphosphate and I_2: ETc 80% irrigation regime for both seasons. The highest faba Plant height (cm) of 130 cm was obtained by P_2 I_1 granular calcium superphosphate and I_1: ETc 100**%** for both seasons.

Irrigation effect: Results in Table 8 and Figure 2 show that the main effect of the irrigation regime shows that $I_1 > I_3 > I_2$ with average increases of 8.5 and 8.5% for I1 over $I_3 > I_2$, for two seasons, respectively. The greater Plant height by the I1 treatment was particularly obtained under conditions of the P_2: Granular calcium superphosphate The current results agree with those obtained by Hegab, *et al.* [33], which showed that the application of 0.60 of (IR) irrigation decreased the vegetative growth. In addition, it was revealed that there were no significant differences between 1.00 (IR) and 0.80 (IR) on the plant height; however, 1.00 (IR) and 0.80 (IR) were higher than that obtained by 0.60 (IR) these results similar to the current results. The current results agree with those obtained by Fayed, *et al.* [31] who record that the application of 0.60 of (IR) irrigation decreased the vegetative growth as well as biological and seed yields; however, the 1.00 irrigation treatment achieved the greatest grain yield as compared to other irrigation levels. The current results agree with those obtained by Awadalla, *et al.* [30] who reveal that 100 % of ETc of irrigation treatment gave the lower plant height, compared to the irrigation at 60 % of ETc. Gunes, *et al.* [34] presented that the significant growth associated with 100 %, ETc may be due to the high soil moisture content.in addition, it increases water absorption and nutrient uptake reflecting an increase in the photosynthetic rate which results in a growth boost.

P-fertilizer source effect: Results in Table 8 and Figure 2 show that the main effect of the P-fertilizer source shows that $P_0 > P_3 > P_2 > P_1$ with average increases of 3.2, 6.6 and 9% for P0 over $P_3 > P_2 > P_1$ with for two seasons, respectively. The greater Plant height by the P0 treatment was particularly obtained under conditions of the I3: ETc 60%. The current results agree with those obtained. Papakaloudis and Dordas [28] mentioned that the highest plants were observed in the 60 kg ha^{-1} of P_2O_5 fertilizer treatment. The current results agree with those obtained by Zaki, *et al.* [35] who reported that fertilizing the plants with different sources (P) plus *Bacillus megaterium* var phosphatic, (PDB) gave the highest values of Vegetative growth characteristics.

3.3. Number of Branches Plant^{-1}

Results in Table 8 and Figure 3 show that the lowest Number of branches $plant^{-1}$ of 3.33 $plant^{-1}$ cm was obtained by the treatments of P_2I_1 Granular calcium superphosphate and I_1: ETc 100% irrigation regime for both seasons. the highest number of branches $plant^{-1}$ of 6.00 $plant^{-1}$ was obtained by the treatments of P_1 I_1 Powdered calcium superphosphate and I_1: ETc 100% irrigation regime for both seasons.

Irrigation effect: Table 8 and Figure 3 show that the main impact of the irrigation regime shows that $I_2 > I_3 > I_1$ with average increases of 12.8 and 13.1% for I_2 over I_3 and I_1, for two seasons, respectively. A greater number of branches of $plant^{-1}$ was found in treatment I_2, especially under P_0 conditions: no P-fertilization. The current results disagree with those obtained by Awadalla, *et al.* [30] revealing that 100 % of ETc of irrigation treatment gave a higher number of branches compared to the irrigation at 60 % of ETc.

P-fertilizer source effect: Results in Table 8 and Figure 3 show that the main impact of P-fertilizer source shows that $P_1 > P_3 > P_0 > P_2$ with average increases of 5.6, 21.3 and 26.6 % for P_1 over $P_3 > P_0 > P_2$ with for two seasons, respectively. The greater number of branches $plant^{-1}$ by the P_1 treatment was obtained of the I_1: ETc 100 %. The current results agree with those obtained by Gizawy and Mehasen [36] who mentioned that the application of P_2O_5 mixed with phosphate-dissolving bacteria PDB markedly increased the number of branches.

Table-8. Average plant height (cm) and Number of branches $plant^{-1}$ a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons.

Irrigation treatments		Plant height (cm)				
		P-fertilizer sources				
		P_0	P_1	P_2	P_3	Mean
I_1		121.55 c	121.95 c	130.25 a	125.25 b	124.75 A
I_2		115.55 d	111.55 e	101.55 f	113.95 de	110.65 C
I_3		129.25 a	102.55 f	111.95 e	115.95 d	114.93 B
Mean		122.12 A	112.02 D	114.58 C	118.38 B	
LSD at 5%	A	1.571				
	B	1.905				
	AB	3.298				
Irrigation treatments		Number of branches $plant^{-1}$				
		P-fertilizer sources				
		P_0	P_1	P_2	P_3	Mean
I_1		5.33 e	7.00 a	3.66 g	6.33 c	5.58 C
I_2		6.66 b	6.33 c	6.00 f	6.33 c	6.33 A
I_3		4.33 f	6.33 c	6.00 d	6.00 d	5.67 B
Mean		5.44 C	6.55 A	5.22 D	6.22 B	
LSD at 5%	A	0.074				
	B	0.850				
	AB	0.148				

Figure-2. Average plant height (cm) as a response to irrigation level, and P-fertilized source for 2022/2023 and 2023/2024 seasons

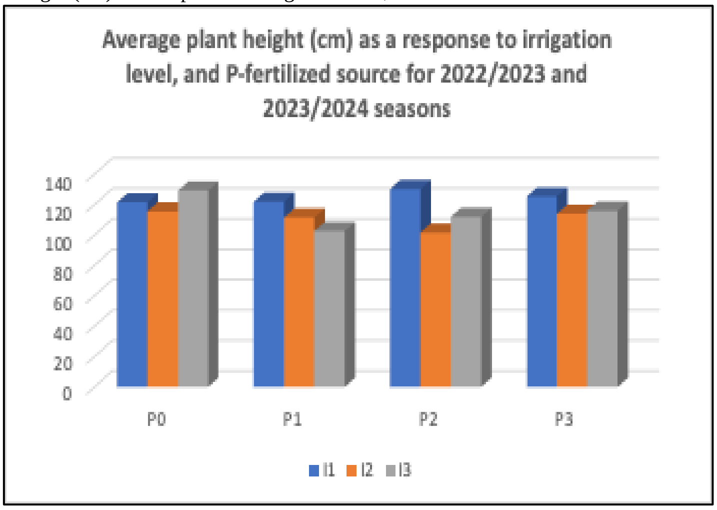
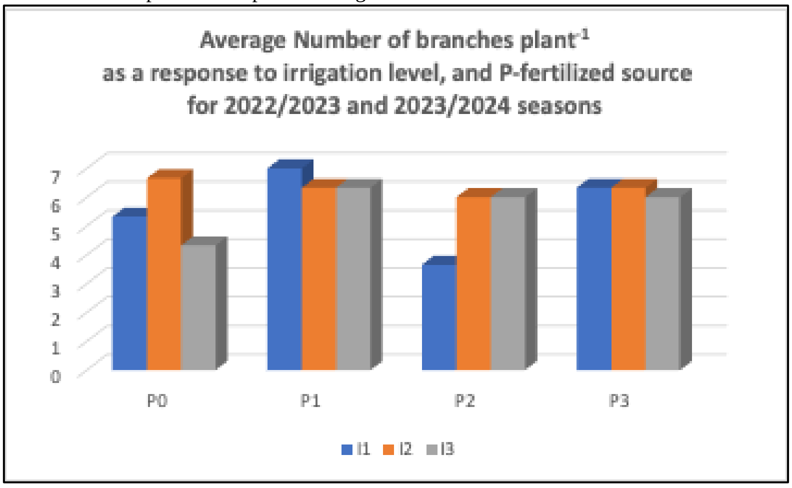


Figure-3. Average Number of branches plant-1 a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons.



3.4. Number of Pods Plant^{-1}

Results in Table 9 and Figure 4 show that the lowest number of pods plant^{-1} of 15.43 plant^{-1} was obtained by the treatments of P_2 I_3 Granular calcium superphosphate and I_3: ETc 60 % irrigation regime for both seasons. the highest Number of pods plant^{-1} of 26.43 plant^{-1} was obtained by the treatments of P_3 I_3 Rock phosphate (Powdered) and I_3: ETc 60 % irrigation regime for both seasons.

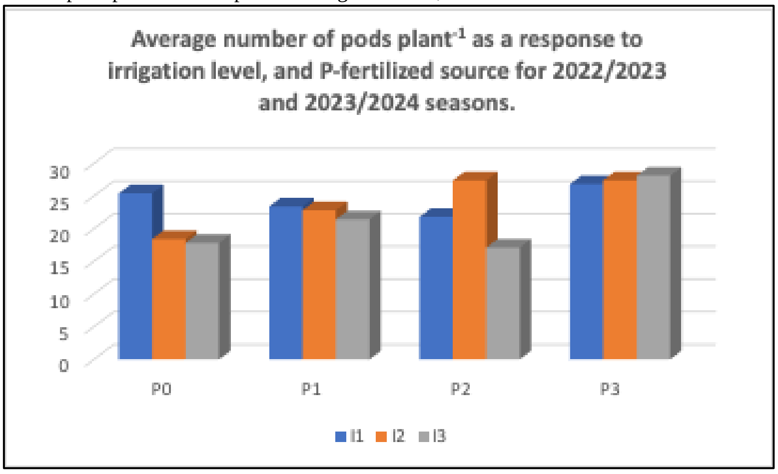
➮ **Irrigation effect:** Results in Table 9 and Figure 4 show that the main impact of the irrigation regime shows that $I_1 > I_2 > I_3$ with average increases of 15.5% for I_1 and I_2 over I_3, for two seasons, respectively. The greater number of pods plant^{-1} by the I_3 treatment was particularly obtained of the P_3: Rock phosphate (Powdered).

➮ **P-fertilizer source effect:** Results in Table 9 and Figure 4 show that the main impact of the P-fertilizer source is that $P_3 > P_1 = P_2 > P_0$ with average increases of 23 and 24.2 % for P_3 over $P_1 = P_2 > P_0$ with for two seasons, respectively. The greater number of pods plant^{-1} by the P_3 treatment was particularly obtained under the I_3: ETc 60% conditions. The current results agree with those obtained by Gizawy and Mehasen [36] mentioned that the appling of P_2O_5 mixed with phosphate-dissolving bacteria markedly increased the number of pods/plants.

Table-9. Average number of pods plant^{-1} as a response to irrigation level, and P-fertilized source for 2022/2023 and 2023/2024 seasons.

Irrigation treatments		**Number of pods plant^{-1}**				
		P-fertilizer sources				
		P_0	**P_1**	**P_2**	**P_3**	**Mean**
I_1		25.43 c	23.43 d	21.83 e	26.83 b	24.38 A
I_2		18.43 f	22.83 d	27.43 b	27.43 b	24.03 B
I_3		17.83 f	21.43 e	17.13 g	28.13 a	21.13 C
Mean		18.86 D	20.86 B	20.43 C	25.76 A	
LSD at 5%	**A**	0.325				
	B	0.375				
	AB	0.650				

Figure-4. Average number of pods plant^{-1} as a response to irrigation level, and P-fertilized source for 2022/2023 and 2023/2024 seasons



3.5. Weight of Green Pods (g plant^{-1})

Table 10 and Figure 5 show that the lowest number of weights of green pods was obtained by the treatments of P_2 I_3 Granular calcium superphosphate, and I_3: ETc 60% irrigation regime for both seasons. The highest Weight of green pods was obtained by the treatments of P_3 I_2 Rock phosphate (Powdered) and I_2: ETc 60% irrigation regime for both seasons.

- **Irrigation effect:** Table 10 and Figure 5 show that the main impact of the irrigation regime shows that $I_2 > I_1 > I_3$ with average increases of 13.8 and 60.9% for I_2 and I_1 over I_3, for two seasons, respectively. The greater weight of green pods by the I_2 treatment was particularly obtained under of the P_3: Rock phosphate (Powdered).
- **P-fertilizer source effect:** Results in Table 10 and Figure 5 show that the main impact of the P-fertilizer source show gave a higher yield than the nonfertilized one. The $P_3 > P_1 > P_2 > P_0$ average increases of 20.0, 28.1, and 33.3% for P_3 over $P_1 > P_2 > P_0$ for two seasons, respectively. The greater Weight of green pods by the P_3 treatment was obtained under conditions of the I_2: ETc 80%.

3.6. Yield of Faba Bean Green Pods (ton ha^{-1})

Results in Table 10 and Figure 6 show that the lowest Yield was obtained by P_2I_3 the treatments of P_2: Granular calcium superphosphate and I_2: ETc 60 % irrigation regime for both seasons. The highest Weight of green pods was obtained by the treatments of P_3 I_2 Rock phosphate (Powdered) and I_2: ETc 80% irrigation regime for both seasons.

- **Irrigation effect:** Results in Table 10 and Figure 6 show that the main effect of the irrigation regime shows that $I_2 > I_1 = I_3$ with average increases of 39 and 45% for I_2 over I_1 and I_3, for two seasons, respectively. The greater yield obtained by the I_2 treatment was particularly obtained under conditions of the P3: Rock phosphate (Powdered) reflected 80% of ETc at the significant one followed by 100% and 60% of ETc.The current results disagree with those obtained by Hegab, *et al.* [33] who mentioned that the 1.00 irrigation water requirement treatments gave the highest grain yield.
- **P-fertilizer source effect:** Results in Table 10 and Figure 6 show that the main effect of the P-fertilizer source show gave a higher yield than the nonfertilized one. The $P_3 > P_1 = P_2 > P_0$ with average increases of 13.2, 11.8, and 25.3% for P_3 over $P_1 = P_2 > P_0$ for two seasons, respectively. The greater yield obtained by the P_3 treatment was particularly obtained under conditions of the I_2: ETc 80%. The results reveal the P- Rock phosphate (Powdered) gave the highest yield referring that the current results disagree with those obtained by Attia [37] who mentioned that the 120 kg P_2O_5 ha^{-1} of calcium superphosphate gave the highest yield under the environmental conditions. The results agree with those obtained by Keneni and M. [38] indicating a positive and significant correlation between seed yield and number of pods\ plants. The current results agree with those obtained by Zaki, *et al.* [35] mentioned that fertilizing the plants with different sources (p) plus (PDB) gave the highest values of yield. The results are similar to those obtained by Chtouki, *et al.* [32] who reported that the P fertilizers application significantly improved water productivity, especially under water stress conditions, results support the importance of adequate P nutrition in the mitigation of drought stress effects on plant growth and productivity [39].

Table-10. Average weight of green pods (g plant^{-1}) and yield of faba bean green pods (ton ha^{-1}) as a response to irrigation level, and P-fertilized source for 2022/2023 and 2023/2024 seasons

Irrigation treatments		Weight of green pods (g plant^{-1})				
		P-fertilizer sources				
		P_0	P_1	P_2	P_3	Mean
I_1		542.55 d	453.70 e	440.00 f	536.95 d	493.30 B
I_2		381.95 h	554.60 c	575.05 b	733.15 a	561.19 A
I_3		327.70 i	382.15 h	287.10 j	398.50 g	348.86 C
Mean		417.40 D	463.48 B	434.05 C	556.20 A	
LSD at 5%	**A**	2.770				
	B	3.198				
	AB	5.540				
Irrigation treatments		**Yield of faba bean green pods (ton ha^{-1})**				
		P-fertilizer sources				
		P_0	P_1	P_2	P_3	Mean
I_1		22.56 h	25.55 f	27.65 de	24.05 g	24.95 B
I_2		27.15 e	36.75 b	33.95 c	40.85 a	34.68 A
I_3		25.20 fg	21.55 h	20.25 i	28.80 d	23.95 C
Mean		24.97D	27.95B	27.28C	31.23A	
LSD at 5%	**A**	0.5772				
	B	0.667				
	AB	1.154				

Figure-5. Average weight of green pods (g plant^{-1}) as a response to irrigation level, and P-fertilized source for 2022/2023 and 2023/2024 seasons

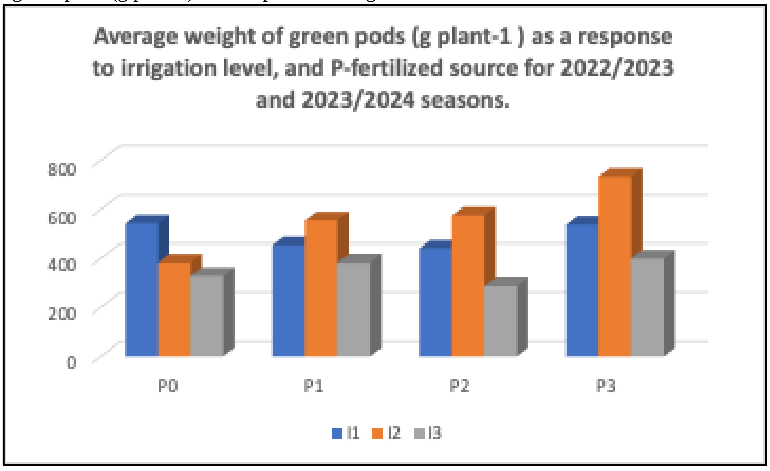
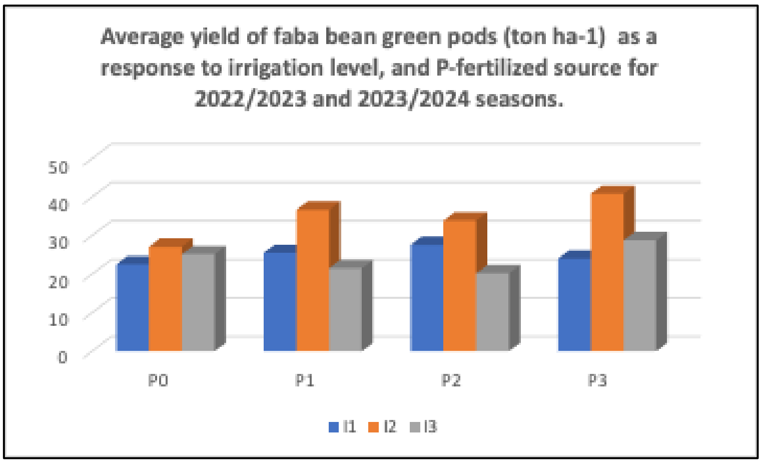


Figure-6. Average Yield of faba bean green pods (ton ha^{-1}) as a response to irrigation level, and P-fertilized source for 2022/2023 and 2023/2024 seasons



3.7. Straw Faba Bean NPK Uptake

3.7.1. Straw Faba Bean N- Uptake

Table 11 and Figure 7 show that the lowest N uptake was obtained by P_1I_3 treatments; P_1: granular calcium superphosphate and I_2: ETc irrigation system at 60% in both seasons. The highest N uptake was obtained with fertilization treatments P0 I1 No P and I1: ETc irrigation system 100% for both seasons.

➢ **Irrigation effect:** Results in Table 11 and Figure 7 show that the main effect of the irrigation regime shows that $I_1 > I_2 > I_3$ with average increases of 12.7 and 78.0% for I_1 over $I_2 > I_3$, for two seasons, respectively. The greater N-uptake by the I_1 treatment was particularly obtained under conditions of the P_0: No P- fertilization.

➢ **P-fertilizer source effect:** Results in Table 11 and Figure 7 show that the main effect of P-fertilizer source shows that $P_0 > P_1 > P_2 > P_3$ with average increases of 4.1, 10.0 and 16.9 % for P_0 over $P_1 > P_2 > P_3$ for two seasons, respectively. The greater N-uptake by the P_0 treatment was particularly obtained under conditions of the I_1: ETc 100 %.

3.7.2. Straw Faba Bean P- Uptake

Results in Table 11 and Figure 8 show that the lowest P-uptake was obtained by P_3I_3 in the treatments of P_0: No P- fertilization and I_3: ETc 100% irrigation regime for both seasons. The highest P-uptake was obtained by the treatments of P_2 I_2 No P-fertilization and I_2: ETc 80% irrigation regime for both seasons.

➢ **Irrigation effect:** Results in Table 11 and Figure 8 show that the main impact of the irrigation regime shows that $I_2 > I_1 > I_3$ with average increases of 6.2 and 49.7% for I_2 over $I_1 > I_3$, for two seasons, respectively. The greater P-uptake by the I_1 treatment was particularly obtained under conditions of the P_0: No P- -fertilization. The current results agree with those obtained by [40] demonstrated that the reduction in soil water content affected the focus of phosphate which can explain the insignificant P-uptake amid the powdered calcium superphosphate and powdered rock phosphate. Reducing water volume would also reduce the rate at which the solution-phosphate is replenished through desorption [41, 42], and mass solution flow [43]. The effect of reduced phosphate supply could act on the plant independently of its need for water aside from mass solution flow.

➢ **P-fertilizer source effect:** Results in Table 11 and Figure 8 show that the main impact of the P-fertilizer source shows that $P_2 > P_1 = P_0 = P_3$ with average increases of 20.0, 21.6 and 22.9% for P_2 over P_1, P_0, and P_3 for two seasons, respectively. The greater P-uptake by the P_2 treatment was particularly obtained under conditions of the I_2: ETc 80%.

3.7.3. Straw Faba Bean K- Uptake

Table 11 and Figure 9 show that the lowest k-uptake was obtained by P_0 I_3 in the treatments of P_0: No P-fertilization and I_3: ETc 60% irrigation regime for both seasons. The highest k-uptake was obtained by the treatments of P_1 I_1: Powdered calcium superphosphate and I_1: ETc 100% irrigation regime for both seasons.

➢ **Irrigation effect:** Results in Table 11 show that the main effect of the irrigation regime shows that $I_1 > I_2 > I_3$ with average increases of 41.3 and 95.5% for I_1 over $I_2 > I_3$, for two seasons, respectively. The greater k-uptake by the I_1 treatment was particularly obtained under conditions of the P_1 Powdered calcium superphosphate. The current results agree with those obtained by Chtouki, *et al.* [32] mention that the under a full irrigation regime (I_1) absorbed k-uptake more than those grown under medium and severe water stress compared to the unfertilized treatment.

➢ **Fertilizer source effect:** Results in Table 11 and Figure 9 show that the main impact of the P-fertilizer source shows that $P_2 > P_1 > P_0 > P_3$ with average increases of 14.4, 25.7 and 40.6 % for P_2 over P_1, P_0, and P_3 for two seasons, respectively. The greater k-uptake by the P_1 treatment was obtained of the I_1: ETc 100 %.

Table-11. Average straw NPK uptake (kg ha^{-1}) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons.

Irrigation treatments		**N- uptake in straw of faba bean (kg ha^{-1})**				
		P-fertilizer sources				
		P_0	**P_1**	**P_2**	**P_3**	**Mean**
I_1		136.94 a	134.09 b	106.78 d	56.86 j	108.67 A
I_2		78.10 g	85.03 f	96.96 e	125.71 c	96.45 B
I_3		70.80 h	55.34 j	55.99 j	62.02 i	61.04 C
Mean		95.28 A	91.49 B	86.58 C	81.53 D	
LSD at 5%	**A**	1.209				
	B	1.396				
	AB	2.417				
Irrigation treatments		**P- uptake in straw of faba bean (kg ha^{-1})**				
		P-fertilizer sources				
		P_0	**P_1**	**P_2**	**P_3**	**Mean**
I_1		15.31 b	13.86 d	11.22 e	10.50 f	12.72 B
I_2		8.20 h	10.37 f	20.93 a	14.56 c	13.52 A
I_3		9.96 fg	9.67 g	8.51 h	8.04 h	9.05 C
Mean		11.16 B	11.30 B	13.55 A	11.03 B	
LSD at 5%	**A**	0.279				
	B	0.322				
	AB	0.557				
Irrigation treatments		**K- uptake in straw of faba bean (kg ha^{-1})**				
		P-fertilizer sources				
		P_0	**P_1**	**P_2**	**P_3**	**Mean**
I_1		182.81 b	188.55 a	181.05 b	111.39 e	165.95 A
I_2		104.43 f	100.54 g	127.36 d	137.47 c	117.45 B

I_3		59.55 i	91.85 h	127.37 d	61.13 i	84.97 C
Mean		115.59 C	126.98 B	145.26A	103.33D	
LSD at 5%	**A**	1.719				
	B	1.985				
	AB	3.438				

Figure-7. Average straw N uptake (kg ha^{-1}) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons.

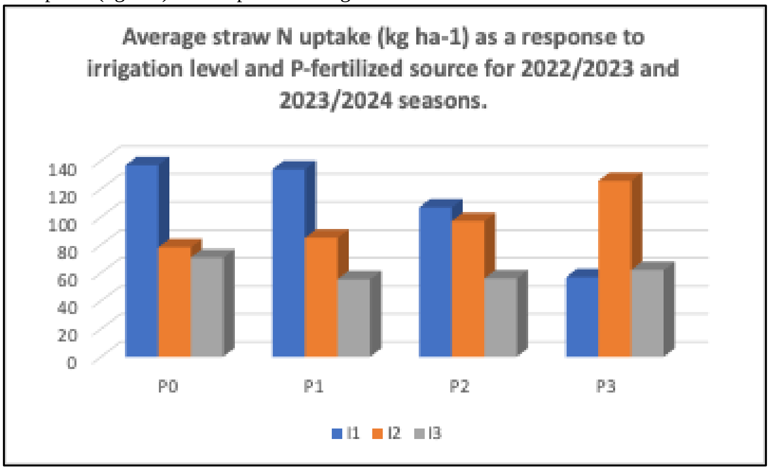


Figure-8. Average straw P uptake (kg ha^{-1}) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons

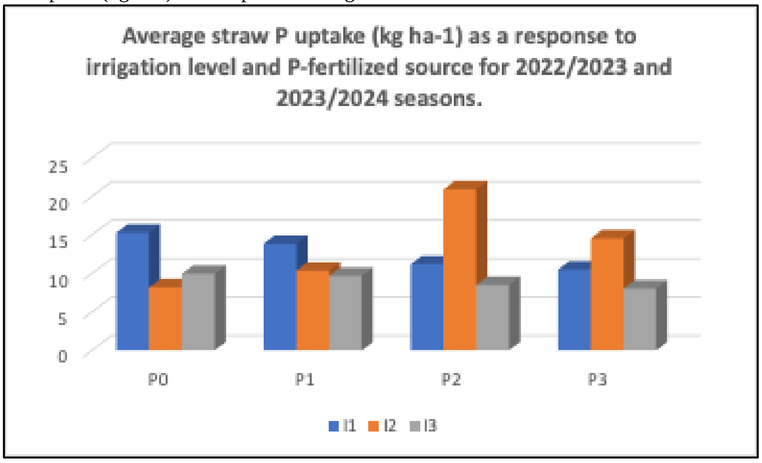
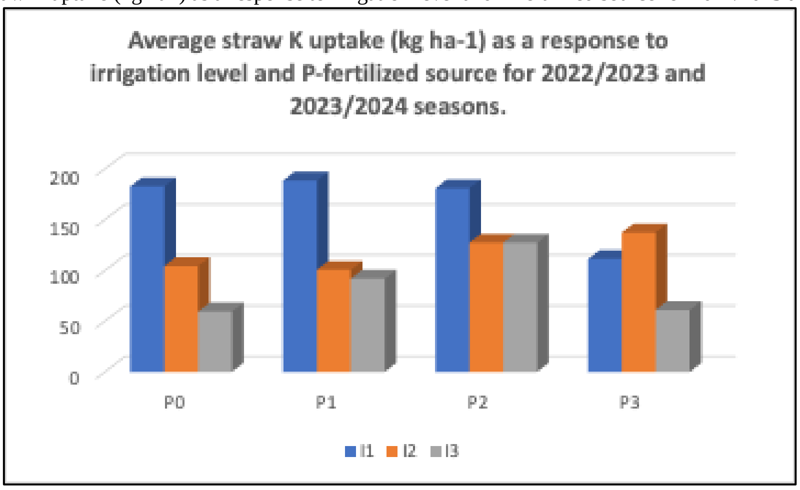


Figure-9. Average straw K uptake (kg ha^{-1}) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons



3.8. Seeds Faba Bean NPK Uptake

3.8.1. Seeds Faba Bean N Uptake

Results in Table 12 and Figure 10 show that the lowest N-uptake was obtained by P_3 I_1 the treatments of P_3: Rock phosphate (Powdered and I_1: ETc 100 % irrigation regime for both seasons. The highest n-uptake was obtained by the treatments of P_3 I_2: Rock phosphate (Powdered) and I_2: ETc 80% irrigation regime for both seasons.

- **Irrigation effect:** Results in Table 12 and Figure 10 show that the main effect of the irrigation regime shows that $I_2 > I_3 > I_1$ with average increases of 51.9 and 99.4% for I_2 over $I_3 > I_1$, for two seasons, respectively. The greater N-**u**ptake by the I_2 treatment was particularly obtained under conditions of the P_3: Rock phosphate (Powdered). The current results agree with those obtained by Chtouki, *et al.* [32] mentioned that the under a full irrigation regime (I_1) absorbed much more macro than those grown under medium and severe water stress compared to the unfertilized treatment.

- **P-fertilizer source effect:** Results in Table 12 and Figure 10 show that the main effect of the P-fertilizer source shows that $P_3 > P_1 > P_0 > P_2$ with average increases of 3.3, 13.3 and 15% for P_3 over P_1, $P_{0,}$ and P_2 for two seasons, respectively. The greater N-uptake by the P_3 treatment was particularly obtained under conditions of the I_2: ETc 80%. The current results agree with those obtained by Gizawy and Mehasen [36] who mentioned that the application of P_2O_5 mixed with phosphate dissolving bacteria PDB increased N uptake.

3.8.2. Seed Faba Bean P Uptake

Results in Table 12 and Figure 11 show that the lowest p-uptake was obtained by P_2 I_3 the treatments of P_2: Granular calcium superphosphate and I_3: ETc 60% irrigation regime for both seasons. The highest p-uptake was obtained by the treatments of P_3 I_2: Rock phosphate (Powdered) and I_2: ETc 80% irrigation regime for both seasons.

- **Irrigation effect:** Results in Table 12 and Figure 11 show that the main effect of the irrigation regime shows that $I_2 > I_1 > I_3$ with average increases of 31.1 and 36.3% for I_2 over I_1 and I_2, for two seasons, respectively. The greater p-uptake by the I_2 treatment was particularly obtained under conditions of the P_3: Rock phosphate (Powdered). The current results have an opposite trend (80% of ETc) with those obtained by Chtouki, *et al.* [32] who record that the P application significantly improved P uptake, with increasing values under non-limited water supply conditions (75% of Field capacity).
- **P-fertilizer source effect**: Results in Table 12 and Figure 11 show that the main effect of the P-fertilizer source shows that $P_3 > P_1 > P_2 > P_0$ with average increases of 6.4, 12.8 and 21.9% for P_3 over P_1, $P_{2,}$ and P_3 for two seasons, respectively. The greater p-uptake by the P_3 treatment was particularly obtained under conditions of the I_2: ETc 80%. Chtouki, *et al.* [32] reported that the increased P uptake treatment was accompanied by significant increases in nutrient uptake (N and K).

3.8.3. Seed Faba Bean Potassium Uptake

Results in Table 12 and Figure 12 show that the lowest K-uptake was obtained by P_1I_1 in the treatments of P_1: Powdered calcium superphosphate and I_1: ETc 100% irrigation regime for both seasons. The highest K-uptake was obtained by the treatments of P_1 I_2 P_1: Powdered calcium superphosphate and I_2: ETc 80% irrigation regime for both seasons. The current results disagree with those obtained by Chtouki, *et al.* [32] mentioned that the P- application. and full irrigation regime (I_1) absorbed k-uptake than those grown under medium and severe water stress as compared to the unfertilized treatment.

- **Irrigation effect:** Results in Table 12 and Figure 12 show that the main effect of the irrigation regime shows that $I_2 > I_3 > I_1$ with average increases of 29.5 and 40.3% for I_2 over I_3 and I_1, for two seasons, respectively. The greater K-uptake by the I_2 treatment was particularly obtained under conditions of the P1: Powdered calcium superphosphate**.**
- **P-fertilizer source effect:** Results in Table 12 and Figure 12 show that the main effect of the P-fertilizer source shows that $P_3 > P_1 > P_2 = P_0$ with average increases of 28.9 and 33.7% for P_3 over P_1, and $P_2 = P_3$ for two seasons, respectively. The greater k-uptake by the P_1 treatment was particularly obtained under conditions of the I_2: ETc 80%.

Table-12. Average faba bean Seed NPK uptake (ton ha^{-1}) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons.

Irrigation treatments		N- uptake in seed of faba bean (kg ha^{-1})				
		P-fertilizer sources				
		P_0	P_1	P_2	P_3	Mean
I_1		93.67 j	103.63 i	144.29 e	58.03 k	99.91 C
I_2		160.87 c	226.87 b	136.03 f	264.77 a	197.13 A
I_3		151.54 d	114.19 h	119.86 g	136.44 f	130.51 B
Mean		135.36 C	148.23 B	133.39 D	153.08 A	
LSD at 5%	A	2.066				
	B	2.386				
	AB	4.132				
Irrigation treatments		P- uptake in seed of faba bean (kg ha^{-1})				
		P-fertilizer sources				
		P_0	P_1	P_2	P_3	Mean
I_1		13.54 hi	15.53ef	16.08 e	14.11 gh	14.81 B
I_2		15.38 f	21.22 b	18.84 c	22.20 a	19.41 A
I_3		14.69 g	13.22 i	12.22 j	16.85 d	14.24 C
Mean		14.54 D	16.66 B	15.71 C	17.72 A	
LSD at 5%	A	0.295				
	B	0.341				
	AB	0.591				

Irrigation treatments		K- uptake in seed of faba bean (kg ha^{-1})				
		P-fertilizer sources				
		P_0	P_1	P_2	P_3	Mean
I_1		48.24 h	40.54 j	53.26 g	66.26 d	52.08 C
I_2		55.75 f	83.64 a	70.58 c	82.34 a	73.08 A
I_3		61.08 e	48.38 h	42.48 i	73.78 b	56.43 B
Mean		55.02 C	57.52 B	55.44 C	74.13 A	
LSD at 5%	A	0.837				
	B	0.966				
	AB	1.673				

Figure-10. Average faba bean Seed N uptake (ton ha^{-1}) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons

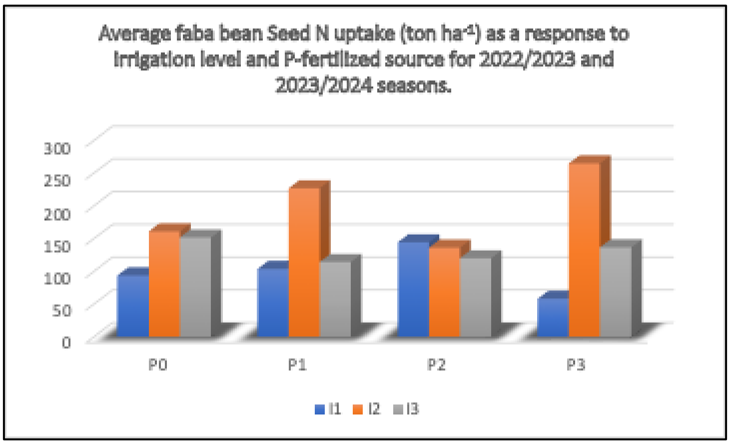


Figure-11. Average faba bean Seed P uptake (ton ha^{-1}) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons

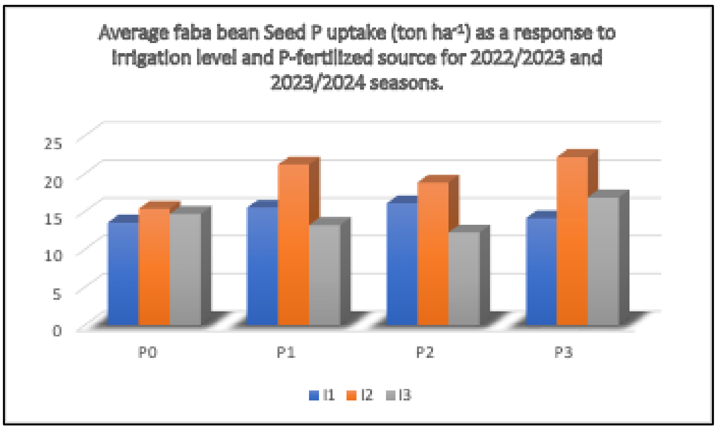
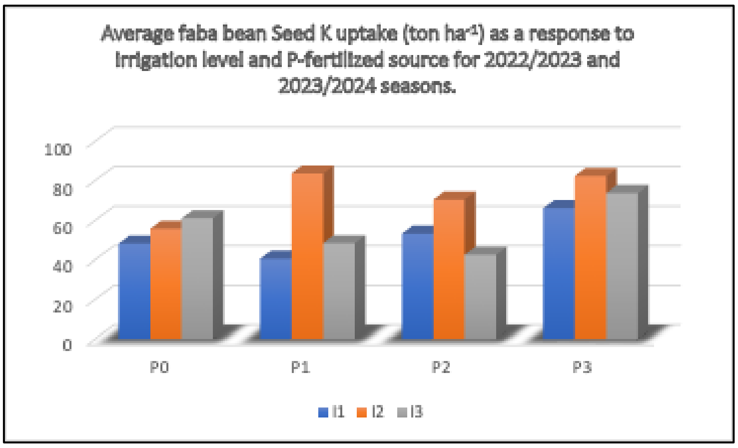


Figure-12. Average faba bean Seed K uptake (ton ha^{-1}) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons



3.9. Contents of Protein in Faba Bean Straw

Table 13 and Figure 13 shows that the lowest Protein % contents were obtained by P_1I_3 in the treatments of P_1: Powdered calcium superphosphate and I_2: Etc 60% irrigation regime for both seasons. The highest Protein content was obtained by the treatments of P_0 I_1 P_0: No P- fertilization and I_1: ETc 100% irrigation regime for both seasons.

- **Irrigation effect:** Table 13 show that the main effect of the irrigation regime shows that $I_1 > I_2 > I_3$ with average increases of 17.4 and 29.5% for I_1 over I_2 and I_3, for two seasons, respectively. The greater Protein% contents by the I_1 treatment were particularly obtained under conditions of the P_0: No P- fertilization, the following study confirmed this [44, 45].
- **P-fertilizer source effect:** Results in Table 13 show that the main effect of fertilizer source shows that $P_0 > P_1 > P_2 > P_3$ with average increases of 5.3, 13.6 and 19.7% for P_0 over P_1, P_2, and P_3 for two seasons, respectively. The greater Protein % content by the P_0 treatment was particularly obtained under conditions of the I_1: ETc 100%.

3.10. Contents of Protein (%) in Faba Bean Seeds

Results in Table 13 and Figure 14 show that the lowest Protein contents were obtained by P_3I_1 in the treatments of P_3: Rock phosphate (Powdered) superphosphate and I_1: ETc 100% irrigation regime for both seasons. The highest Protein contents were obtained by the treatments of P_3 I_2: Rock phosphate (Powdered) and I_1: ETc 80% irrigation regime for both seasons.

- **Irrigation effect:** Results in Table 13 show that the main effect of the irrigation regime shows that $I_2 = I_3 > I_1$ with average increases of 24 % for I_2 and I_3 over I_1, for two seasons, respectively. The greater Protein % contents by the I_2 and I_3 treatments were particularly obtained under conditions of the P_1: powdered calcium superphosphate and P3: Rock phosphate (Powdered). The current results disagree with those obtained by Hegab, *et al.* [33] who indicated that the highest value of protein contents in the faba bean seeds was obtained by the lowest irrigation level (0.60IR). El-Maghraby and Abd El.-Hay [46], concluded that the protein percentage of faba bean and some of the other legumes differed according to irrigation regimes, low available soil moisture increased the crude protein percentage of faba bean. However, the current results are not similar to those finding obtained by El-Ghobashy and Youssef [47] who reported that at the highest water stress (80% depletion) faba bean gave the highest protein percentage The same finding was obtained by Hanna-Fardoas and Abdel-Nour [48] who mentioned that water deficit increased seed protein compared with wet conditions. Interpretation of these findings could be due to that protein is considered a good indicator for plant tolerance to water drought as an adequate water supply caused hydrolysis and catabolism in proteins and released free amino acids and ammonia as well as proline [49]. The current results agree with those obtained by Awadalla, *et al.* [30] who mentioned that the highest values were obtained by 60 % ETc The highest values of (WUE), (WCP) and seed quality (protein content) occurred with 60 % ETc (Ir1) of irrigation water level.
- **P-fertilizer source effect**: Results in Table 13 show that the main effect of the P-fertilizer source shows that $P_0 > P_1 > P_2 > P_3$ with average increases of 3.6, 6.5 and 18.6% for P_0 over P_1, P_2, and P_3 for two seasons, respectively. The greater protein by the P_1 treatment was particularly obtained under conditions of the I_3: ETc 100%. The current results agree with those obtained by Gizawy and Mehasen [36], which showed that the application of P_2O_5 mixed with phosphate-dissolving bacteria PDB markedly increased the protein.

Table-13. Average Faba bean straw and seed protein (%) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons.

Irrigation treatments		Protein % in straw of faba bean				
		P-fertilizer sources				
		P_0	P_1	P_2	P_3	Mean
I_1		11.30 a	10.70 ab	10.72 ab	5.01 f	9.44 A
I_2		7.70 cde	8.13 cd	6.99 de	9.32 bc	8.04 B
I_3		8.01 cd	6.84 de	6.07 ef	8.24 cd	7.29 B
Mean		9.01 A	8.56 AB	7.93 BC	7.53 C	
LSD at 5%	A	0.837				
	B	0.966				
	AB	1.673				
Irrigation treatments		Protein % in seed of faba bean				
		P-fertilizer sources				
		P_0	P_1	P_2	P_3	Mean
I_1		20.61e	20.18 e	26.09 c	11.66 f	19.64 C
I_2		29.80 b	31.11 ab	20.03 e	32.65 a	28.40 A
I_3		30.24 b	26.53 c	29.59 b	23.67 d	27.51 B
Mean		26.88 A	25.94 AB	25.24 B	22.66 C	
LSD at 5%	A	0.828				
	B	0.957				
	AB	1.657				

Figure-13. Average Faba bean seed protein (%) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons.

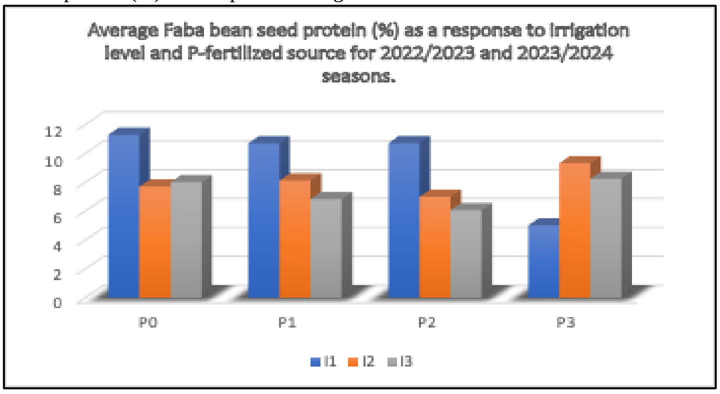
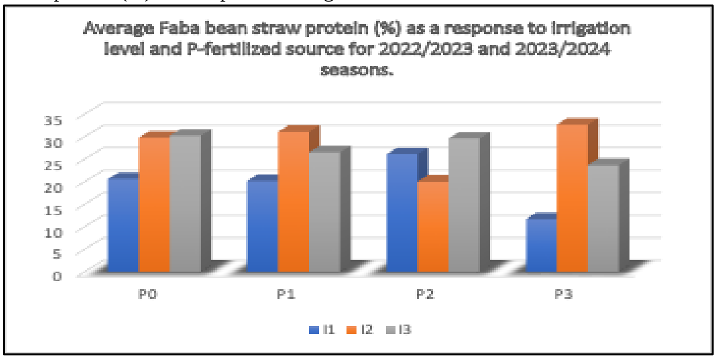


Figure-14. Average Faba bean straw protein (%) as a response to irrigation level and P-fertilized source for 2022/2023 and 2023/2024 seasons



10. Conclusion

To raise the efficiency of irrigation water, and the effectiveness of fertilizers, especially phosphate fertilizers. It can be recommended that 80% of ETc (I_2), with rock phosphate powder (P_3) immunized by *B. megaterium* (phosphate dissolving bacteria) to improve soil properties and achieve high faba bean yield. The manuscript also recommends further studies to increase the efficiency of irrigation and fertilization.

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