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THE POSSIBILITY OF REDUCING CHEMICAL PHOSPHATE FERTILIZATION BY USING MYCORRHIZAL INOCULATION AND SEAWEED EXTRACT FOLIAR SPRAYING AND THEIR EFFECTS ON THE GROWTH AND YIELD OF SNAP BEAN PLANTS

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ABSTRACT

Two successive field experiments were carried out at private farm Housh Eisa, El-Behera Governorate, over two summer seasons in 2022 and 2023. This study investigates the effects of varying rates of phosphorus fertilizers, both with and without arbuscular mycorrhizal fungi (AMF), as well as the foliar application of seaweed extract on the snap bean plant (*Phaseolus vulgaris* L.; c.v. Valentino). The experimental design was a randomized complete blocks design (RCBD) in split split-plot arrangement. The main plots were devoted to phosphorus fertilizer doses (0%, 25%, 50%, 75%, 100% of recommended dose), and the sub were allocated for AMF application (with or without), whereas the sub-sub-plots were dedicated to the foliar spray of seaweed extract (0, 2, and 4 g/l). The recorded vegetative growth characters were plant height (cm), shoots fresh and dry weights (g), and yield and its components characters as {pods length (cm), pod diameter (mm), number of pods/plant, pods weight/plant (g), pods yield (ton/fad). The results clearly pointed to a significant effect of the examined treatments on all studied traits, in both seasons of study. Moreover, the results showed that

the most recommended combined treatment was using 75% P-fertilization applied to soil, along with 2 or 4 g/l of seaweed extract in the presence of AMF inoculation, in both seasons. Such treatment will contribute to lessening the use of chemical phosphate fertilizers by reducing the environmental hazards and producing safe snap bean green pods for human consumption.

Keywords: Phosphorus, Seaweed Extract, AMF, Snap Bean.

INTRODUCTION

The snap bean (*Phaseolus vulgaris* L.), also known as the green bean, is an essential legume crop widely cultivated for its nutritious pods. Unlike dry common beans, snap beans are cultivated for both fresh consumption and processing. Snap beans are a substantial source of vitamins, dietary fiber, protein, soluble sugars, and minerals, making them a prevalent vegetable in global human diets (**Menga *et al.*, 2023**). Additionally, snap beans are a high source of antioxidants, such as carotenoids and flavonoids that improve heart health and reduce inflammation (**Lourenço *et al.*, 2019)**. The global snap bean production in 2024 was about 25 million tons, whereas in Egypt, the total production of snap beans was about 270,000 tons in the same year (**FAOSTAT, 2024**). Egypt is considered one of the tenth largest exporters of green beans in the world, a result of its remarkably high productivity rate.

However, soil fertility and nutrient management techniques have a reliable effect on the yield and quality of snap bean crops, with the availability of vital elements such as K, P, and N being crucial (**Yuan *et al.*, 2017**). Phosphorus (P) is one of the most critical nutrients for plant growth, as it is a critical component of biological compounds, including phospholipids, nucleotides, nucleic acids, and phosphoproteins. Phosphate compounds serve as the "carbon currency" within plants **(Ahmed *et al.*, 2018**). It is essential for plant biochemical functions like protein and carbohydrate metabolism and photosynthesis (**Hernández and Munné-**

Bosch, 2015). In croplands, phosphorus availability constraints decrease up to 67% of primary agronomic productivity. (**Dhillon *et al.*, 2017)**. To address these limitations, the practice of excessive phosphorus fertilization is prevalent in agricultural systems globally. This approach seeks to optimize agricultural productivity (**Zou *et al.*, 2022**). Crops only utilize approximately 20% of the applied P fertilizer, despite the increased application (**Jagdeep *et al.*, 2023**). Previous projections have suggested that P reserves may be exhausted within fifty to one hundred years due to their nonrenewable nature (**Ran *et al.*, 2023**). Excessive phosphorus application poses risks to environmental pollution, global food security, and crop quality, primarily due to its antagonistic effects on the availability of micronutrients like iron (**Yang *et al.*, 2024**) and zinc (**Zhang *et al.*, 2021**). It is essential to investigate and apply effective phosphorus fertilization strategies that promote sustainability of production in intensive farming systems.

The demand for organic food and interest in sustainable agriculture have surged because of public concern over the harmful environmental effects of excessive agrichemical use (**Willer *et al.*, 2024; Carrara *et al.*, 2024).** Consequently, it is important to develop methods that improve crop nutrient absorption to mitigate the decline in mineral nutrient inputs associated with organic practices. Seaweed extracts (SWE) and arbuscular mycorrhizal fungi (AMF) are currently crucial tactics to guarantee sustainable agriculture, particularly in dry and semi-arid areas where soils lack organic matter (**De Pascale *et al.*, 2017; Rady *et al.*, 2018**).

In reaction to this demand, investigations into the application of arbuscular mycorrhizal fungi as biofertilizers in agricultural production have intensified (**Al-Amri 2021; El-Shaboury *et al.* 2023; Sadeghi and Aboutalebian, 2024**). Mycorrhizal fungi play a crucial role in the microbial component of different soil nutrient life cycles, specifically carbon, phosphorus, and nitrogen. As a result, they have a significant impact on plant growth, enhancing the nutrition and health of plants through minerals and water. Arbuscular mycorrhizal fungus (AMF) functions as a biofertilizer by promoting plant growth through enhanced uptake of carbon, nitrogen, and phosphorus, while also serving as a bioprotectant against biotic stressors, such as pathogens (**Hou *et al.*, 2020**), and abiotic stressors, including heavy metals, elevated CO_2 levels, and drought (**Dos Santos *et al.*, 2017; Surono and Narisawa, 2021**). Mycorrhizal symbioses involve reciprocal resource exchange between plants and microorganisms. The AMF improves hydromineral nutrition through the incorporation of phosphate nutrition. The photosynthetic products required for these microorganisms' growth are obtained from their host plants in exchange (**Loo *et al.*, 2022**).

Bio-stimulants are applied either foliar or through soil for various crops to enhance plant physiological and metabolic status (**Mariani and Ferrante, 2017**). Seaweed extracts represent a rapidly expanding category of bio-stimulants (**Goñi *et al.*, 2018**) and have demonstrated efficacy in enhancing crops tolerance against drought stress (**Jacomassi *et al.*, 2022; Bashandy *et al.*, 2024**). Most seaweed species utilized for bio-stimulant extract production are categorized as brown algae, particularly *Ascophyllum nodosum* (**Mughunth *et al.*, 2024**). Seaweed extracts contain polysaccharides, polyunsaturated fatty acids, plant hormones, bioactive peptides, abundant proteins, enzymes, and both macro- and micronutrients (**Shukla *et al.*, 2016; Okolie *et al.*, 2018; Mughunth *et al.*, 2024**). In general, seaweed extracts have a direct impact on crop yields by promoting root growth, improving water and nutrient absorption, and optimizing photosynthesis (**Yakhin *et al.*, 2017; Mughunth *et al.*, 2024)**. Extracts from brown algae enhance the activity level of antioxidant enzymes and promote the increase of defense metabolites within cells.

The current research intends to examine the impact of bio-inoculation with AMF and foliar applying of seaweed extract on the vegetative growth and yield and its components of snap beans under varying rates of phosphorus fertilizers.

MATERIAL AND METHODS

Study site and soil properties

Two seasonal field experiments were carried out at a private farm located in Housh Eisa, El-Behira Governorate (30°50'50.3"N 30°18'19.3"E), during the two summer seasons of 2022 and 2023. Prior to the initiation of cultivation, soil samples were taken from the experimental site at a depth of 0-30 cm and analyzed for the physical and chemical characteristics as outlined by **Wilde *et al.* (1985),** as shown in Table 1.

Snap bean planting

The row dimensions for snap bean were 0.60 m wide and 2.0 m long each. The planting space was 15 cm apart. The used cultivar was "Valentino" that obtained from the Egyptian Agriculture Research Center, Ministry of Agriculture, Egypt. The seeds were sown on one side (3 seeds each hill) on March 5^{th} and 10^{th} in 2022 and 2023, respectively. The thinning of seedlings occurred for two weeks after sowing, permitting one plant per hill. The pods were harvested when they attained the appropriate level of maturity in both seasons.

The experimental treatments

Phosphorus fertilization

The phosphorus fertilization treatments were as percentages from the recommended dose (RD) of phosphorus fertilization for snap bean commercial production (30 kg/fad, P_2O_5), which added as calcium superphosphate (12% P_2O_5) were 100% (250 kg/fad.), 75% (187.5 kg/fad.), 50% (125 kg/fad.), 25% (62.5 kg/fad.), and control treatment (without superphosphate fertilization).

Arbuscular mycorrhiza inoculation

Mycorrhizal fungi (AMF) supplied by the Microbial Dept., Soils, Water and Environ. Res. Institute, Agricultural Research Centre, Giza, Egypt. The inoculum was mixed with sterilized peat as a carrier. Before sowing, Snap bean seeds were divided into two parts; half of them were inoculated with AMF, evenly coated with a sticker-like Arabic gum and allowed the air-dry for one hour. The other half of the seeds were sown directly as a control.

Table 1. The physical and chemical properties of soil of the experimental site during the two seasons of study.

Soil property	**First season**	**Second season**
Particle size distribution (%)		
Sand	39.5	40.0
Silt	29.5	29.5
Clay	31.0	30.5
Soil texture	Caly loam	Caly loam
EC dSm^{-1} (soil paste)	0.93	1.03
pH (1:2.5)	7.20	8.40
$CaCO_3$ (%)	3.30	4.62
O.M (%)	1.67	---
SP (%)	30.00	23.00
Available element (mg/kg)		
Nitrogen	70.00	144.00
Phosphorus	16.99	9.38
Potassium	167.00	160.00
Cations (meq/l)		
Ca^{++}	2.50	4.06
Mg^{++}	1.50	3.03
Na^{+}	4.95	2.93
K^{+}	0.32	0.31
Anions (meq/l)		
CO_3	----	----
HCO_3^{-}	0.50	1.42
Cl^{-}	5.50	5.78
SO_4^{-}	3.27	3.13

Seaweed extract

The seaweed extract powder was derived from Technogene company, Egypt. The application of seaweed extract treatments was as a foliar spray. The treatments were control (tap water spray), 2 g/l, 4 g/l. During the two seasons of the study, snap bean plants were sprayed 21 days after the sowing date and again 15 days later. According to the source company, the analysis of seaweed extract used in both seasons (Table 2).

Table 2. The analysis of the seaweed extract used in the experiment.

pH	Alginic acid	Organic matter	K_2O	N	P_2O_5	Water solubility
8 – 9	15 – 18%	45 – 55%	16%	2.5 – 3%	4.5 – 5%	99.1%

Experimental design

The established experimental design was a Randomized Complete Blocks Design (RCBD) in split split-plot arrangement. These treatments included three main factors that were chemical phosphorus fertilization levels (control, 25, 50, 75, and 100% RD) as the main factor, AMF inoculation (with or without) as subplots, and foliar application with seaweed extract (control, 2, and 4 g/l) as sub-subplots. The area of each sub-sub-plot was 6 m^2 (2×3 m), where it contained 5 ridges each. Each sub-sub-plot was surrounded by a guard row to avoid treatment interference. All other snap bean production practices (fertilization, pest control, and weed control) were as recommended by the Egyptian Ministry of Agriculture and Land Reclamation.

Recorded data

Sixty days after planting, during the blooming stage, three plants were chosen randomly from each sub-sub-plot to record the following characteristics:

Vegetative growth traits

Plant height (cm), shoot fresh weight/plant (g), and shoot dry weight/plant (g).

Yield and its components

After a duration of 70 days upon reaching the harvest stage, the yield and its components traits in each treatment were assessed as follows: average pod length and diameter (cm), number of pods/plant, average weight of the pod (g), pods yield/fad. (ton). Pods yield/fad. were estimated by multiplying the pod yield of each plant by the estimated plant density of one faddan, which was 44689 plants, then converting the result from grams/fad. into tons/fad. This density derived from multiplying the number of plants of each sub-sub-plot (67 plants) by the factor of 667 (net area of faddan; 4000 m^2/area of sub sub-plot; 6 m^2).

Statistical analysis

The program used for statistical analysis was Costat (2005) and Analysis of variance (ANOVA) was conducted for all possible comparisons. Then, Duncan's multiple range test and LSD were employed to compare the means at a confidence level of 5%.

RESULTS AND DISCUSSION

Vegetative growth characters

Effect of individual application

The results concerning the main effects of different levels of P-fertilization, AMF inoculation, and foliar application with seaweed extract as well as their interactions on vegetative growth characters of snap bean plant are presented in Tables 3 to 7.

The data presented in Table 3 showed that the main factors were, generally, significantly affecting all studied vegetative growth characters, in both seasons of the study. Concerning phosphorus levels, the mean values reflect significant influence on plant height, shoot fresh weight, and shoot dry weight for snap bean plants. Also, the highest average values were observed at 100% and 75% without a significant difference, in season 2023 only. Both seasons' average increasing percentages due to using 100% and 75% phosphorus (RD), respectively, over the control treatment were 21.66-21.88% and 23.06-22.99% for plant height, 63.25-62.97% and 72.28-72.40% for fresh weight, and 60.51-69.53% and 72.04-72.40% for dry weight.

Table 3: Effect of individual treatment of P-fertilization rate and foliar application with seaweed extract in the presence or absence of AMF on snap bean vegetative growth parameters during 2022 and 2023 seasons.

Treatments	Plant height (cm)		Fresh weight (g)		Dry weight (g)	
	2022	2023	2022	2023	2022	2023
Phosphorus fertilization (%)						
0	33.61^{e}	34.96^{c}	52.41^{e}	54.58^{e}	9.37^{e}	9.82^{e}
25	38.38^{d}	40.12^{b}	67.56^{d}	70.31^{d}	12.05^{d}	12.67^{d}
50	39.56^{c}	41.21^{b}	74.57^{c}	77.71^{c}	12.95^{c}	13.63^{c}
75	40.89^{b}	42.61^{a}	85.56^{b}	88.95^{b}	15.04^{b}	15.80^{b}
100	41.36^{a}	43.00^{a}	90.29^{a}	93.86^{a}	16.12^{a}	16.93^{a}
AMF- inoculation						
Without	38.06^{b}	39.67^{b}	69.69^{b}	72.48^{b}	12.10^{b}	12.72^{b}
With	39.46^{a}	41.10^{a}	78.47^{a}	81.69^{a}	14.11^{a}	14.82^{a}
Seaweed extract (g/l)						
0	38.34^{c}	39.94^{a}	71.30^{c}	74.24^{c}	12.53^{c}	13.13^{c}
2	38.75^{b}	40.36^{a}	74.66^{b}	77.61^{b}	13.26^{b}	13.95^{b}
4	39.18^{a}	40.84^{a}	76.27^{a}	79.40^{a}	13.53^{a}	14.23^{a}

*The mean values with the same letters, within each group, do not differ significantly at the 0.05 level.

In the case of AMF inoculation effect, the mean values in Table 3 revealed that the AMF inoculation significantly and positively affected all studied vegetative growth characters, in both seasons of study, with the exception of inoculation treatment. Both seasons' average increase over the uninoculated treatment for plant height by (3.68-3.60%), fresh weight (12.80-12.71%), and dry weight (16.61-16.60%) due to AMF inoculation, respectively, during the two seasons.

The data illustrated in Table 3 showed the effects of varying levels of foliar spray of seaweed extract on vegetative growth parameters. Increasing levels of seaweed extract significantly enhanced the aforementioned parameters. The highest mean values were recorded at 4 g/l, followed by a lower level of 2 g/l in contrast to the control treatment, with no significant differences observed in certain parameters, such as plant height in the second season.

Effect of dual application

The data presented in Table 4 demonstrate the impact of varying P-fertilizer rates (0, 25, 50, 75, and 100%) in the presence or absence of AMF on vegetative growth parameters. All treatments have a significant effect on the mentioned parameters. The snap bean plants treated with 100% P-fertilizers in conjunction with AMF exhibited the highest mean values for vegetative growth parameters, showing no significant difference when compared to those treated with 75% P-fertilizers alongside AMF. This was followed by the application of 100% P-fertilizers without AMF, in comparison to the other treatments. The rate of increase with the economical treatment 75% P-fertilization + AMF was 26.91-26.9% for plant height, 85.80-85.46% for fresh weight, and 99.41-99.466% for dry weight, respectively in the two seasons.

Table 4: Effect of interaction of P-fertilization rate in the presence or absence of AMF on snap bean vegetative growth parameters during 2022 and 2023 seasons.

Treatments		Plant height cm		Fresh weight g/plant		Dry weight g/plant	
		2022	2023	2022	2023	2022	2023
P_2O_5(%)	AMF						
0	Without	32.81 h*	34.08 f	50.28 i	52.42 i	8.50 i	8.93 g
	With AMF	34.41 g	35.84 e	54.53 h	56.74 h	10.23 h	10.70 f
25	Without	37.70 f	39.38 d	64.75 g	67.29 g	11.83 g	12.47 e
	With AMF	39.05 d	40.87 bcd	70.37 e	73.33 e	12.27 f	12.88 e
50	Without	38.75 e	40.36 cd	68.87 f	71.72 f	12.21 f	12.82 e
	With AMF	40.37 c	42.07 ab	80.27 c	83.70 c	13.70 d	14.45 c
75	Without	40.14 c	41.95 abc	77.71 d	80.69 d	13.13 e	13.82 d
	With AMF	41.64 a	43.26 a	93.42 a	97.22 a	16.95 b	17.79 a
100	Without	40.91 b	42.56 a	86.84 b	90.26 b	14.85 c	15.59 b
	With AMF	41.81 a	43.44 a	93.75 a	97.46 a	17.40 a	18.26 a

* The mean values with the same letters do not differ significantly at 0.05 level.

The interaction between P-fertilization rates and seaweed extract levels applied as foliar treatment had a significant impact on vegetative growth parameters, as indicated by the data listed in Table 5). The data indicated that higher levels of seaweed extract, across all phosphorus fertilization rates, resulted in enhanced vegetative parameters. The data also indicated that the highest mean values for vegetative growth parameters were achieved with the application of P-fertilization at 100% RD in conjunction with 4 g/L of seaweed extract as 41.55-43.14 cm for plant height, 92.19-95.81 g for fresh weight, and 16.49-17.29 g for dry weight. This was closely followed by the same rate of P-fertilizers combined with 2 g/l of seaweed extract, with no significant differences observed between these treatments across both seasons when compared to

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the control treatment. Additionally, at 75% P-fertilization with 2 or 4 g/l seaweed extract, no significant differences were observed in most vegetative parameters.

Table 5: Effect of interaction treatment of P-fertilization rate and seaweed extract on snap bean vegetative growth parameters during 2022 and 2023 seasons.

Treatments		**Plant height (cm)**		**Shoot fresh weight (g)**		**Shoot dry weight (g)**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**
P_2O_5 (%)	**SWE (g/l)**						
0	**0**	33.07^{j}	34.39^{f}	50.81^{l}	52.94^{k}	8.68^{l}	9.05^{i}
	2	33.23^{j}	34.59^{f}	52.04^{k}	54.12^{k}	9.37^{k}	9.85^{h}
	4	34.54^{i}	35.91^{f}	54.37^{j}	56.67^{j}	10.05^{j}	10.55^{g}
25	**0**	38.01^{h}	39.61^{e}	65.13^{i}	67.74^{i}	11.87^{i}	12.44^{f}
	2	38.34^{h}	40.24^{de}	67.77^{h}	70.40^{h}	12.10^{h}	12.74^{ef}
	4	38.79^{g}	40.52^{cde}	69.77^{g}	72.80^{g}	12.18^{h}	12.84^{ef}
50	**0**	39.23^{f}	40.75^{b-e}	71.51^{f}	74.67^{f}	12.43^{g}	13.07^{e}
	2	39.60^{ef}	41.21^{a-e}	75.75^{e}	78.96^{e}	13.07^{f}	13.72^{d}
	4	39.85^{e}	41.68^{a-e}	76.44^{e}	79.50^{e}	13.36^{g}	14.11^{d}
75	**0**	40.39^{d}	42.18^{a-d}	81.67^{d}	84.90^{d}	14.07^{d}	14.80^{c}
	2	41.09^{abc}	42.69^{abc}	86.43^{c}	89.74^{c}	15.48^{c}	16.24^{b}
	4	41.19^{abc}	42.96^{ab}	88.59^{b}	92.23^{b}	15.58^{c}	16.36^{b}
100	**0**	41.02^{c}	42.78^{ab}	87.40^{c}	90.93^{c}	15.58^{c}	16.30^{b}
	2	41.50^{ab}	43.08^{a}	91.29^{a}	94.85^{a}	16.30^{b}	17.19^{a}
	4	41.55^{a}	43.14^{a}	92.19^{a}	95.81^{a}	16.49^{a}	17.29^{a}

* The mean values with the same letters do not differ significantly at 0.05 level.

The data presented in Table (6) illustrates the impact of the interaction between seaweed extract sprayed at concentrations of 0, 2, and 4 g/l, in the presence or absence of AMF, on vegetative growth parameters of snap bean during the years 2022 and 2023. A significant influence on all plant growth parameters (plant height, shoot fresh weight, and shoot dry weight) due to foliar application with SWE was observed, particularly in the presence of

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AMF. The highest significant means for the aforementioned traits were recorded with the use of 4 g/l seaweed extract, followed by 2 g/L, in comparison to the untreated plants, which exhibited the lowest values. This fashion was consistent throughout both seasons.

Table 6: Effect of interaction treatment of seaweed extract in presence or absence of AMF on snap bean vegetative growth parameters during 2022 and 2023 seasons.

Treatments		**Plant height cm**		**Fresh weight g/plant**		**Dry weight g/plant**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**
AMF	**SWE(g/l)**						
Without	**0**	37.72^{e}	39.31^{b}	67.03^{f}	69.73^{f}	11.75^{f}	12.34^{d}
	2	37.95^{e}	39.55^{b}	69.85^{e}	72.56^{e}	12.13^{e}	12.76^{c}
	4	38.51^{d}	40.15^{ab}	72.19^{d}	75.15^{d}	12.43^{d}	13.08^{c}
With AMF	**0**	38.96^{c}	40.58^{ab}	75.57^{c}	78.75^{c}	13.30^{c}	13.93^{b}
	2	39.55^{b}	41.18^{a}	79.47^{b}	82.67^{b}	14.40^{b}	15.13^{a}
	4	39.86^{a}	41.53^{a}	80.36^{a}	83.65^{a}	14.63^{a}	15.38^{a}

* The mean values with the same letters do not differ significantly at 0.05 level.

Effects of triple application

Table (7) depicts the interactive effects of phosphorus mineral fertilization and foliar application of seaweed extract in the presence or absence of arbuscular mycorrhizal fungi (AMF). The incorporation of all assessed treatments significantly influenced the means of all examined growth parameters. The effect was notably pronounced with the 100 followed by 75% RD P-fertilizers treatment, particularly in conjunction with AMF, and foliar application at 2 or 4 g/l, with no significant differences seen among these treatments in any parameters except leaf area. The remaining treatments exhibited median values; a similar trend occurred in both seasons, with a rise in all values.

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Table 7: Interaction effect between P-fertilization rate and foliar applying with seaweed extract in presence or absence of AMF on snap bean vegetative growth parameters during 2022 and 2023 seasons.

Treatments			Plant height (cm)		Fresh weight (g)		Dry weight (g)	
			2022	2023	2022	2023	2022	2023
P_2O_5	AMF	SWE(g/l)						
0	Without	0	32.25^{o}	33.51^{i}	47.87^{r}	49.86^{q}	7.57^{s}	7.98^{n}
		2	32.40^{o}	33.77^{hi}	49.59^{q}	51.59^{p}	8.46^{r}	8.87^{m}
		4	33.79^{n}	34.97^{hi}	53.37^{p}	55.81^{o}	9.47^{q}	9.95^{l}
	With	0	33.90^{n}	35.27^{hi}	53.75^{p}	56.02^{no}	9.78^{p}	10.13^{kl}
		2	34.05^{n}	35.42^{hi}	54.49^{op}	56.65^{no}	10.28^{o}	10.83^{jk}
		4	35.29^{m}	36.84^{gh}	55.37^{o}	57.54^{n}	10.63^{n}	11.15^{j}
25%	Without	0	37.43^{l}	39.09^{fg}	61.79^{n}	64.19^{m}	11.62^{m}	12.19^{i}
		2	37.44^{l}	39.18^{efg}	65.27^{m}	67.71^{l}	11.90^{l}	12.59^{h}
		4	38.23^{k}	39.87^{d-g}	67.19^{l}	69.97^{k}	11.96^{l}	12.62^{hi}
	With	0	38.59^{jk}	40.12^{c-f}	68.47^{kl}	71.28^{jk}	12.12^{kl}	12.70^{hi}
		2	39.23^{hi}	41.31^{a-f}	70.28^{j}	73.09^{i}	12.29^{jk}	12.88^{hi}
		4	39.34^{h}	41.17^{a-f}	72.36^{i}	75.62^{h}	12.40^{j}	13.05^{gh}
50%	Without	0	38.39^{k}	39.84^{d-g}	67.56^{l}	70.47^{k}	12.13^{kl}	12.70^{hi}
		2	38.73^{ijk}	40.24^{b-f}	69.43^{jk}	72.32^{ij}	12.24^{jk}	12.88^{hi}
		4	39.12^{hij}	41.01^{a-f}	69.61^{jk}	72.39^{ij}	12.25^{jk}	12.87^{hi}
	With	0	40.07^{fg}	41.67^{a-f}	75.46^{h}	78.88^{g}	12.74^{i}	13.44^{fgh}
		2	40.47^{c-f}	42.18^{a-f}	82.07^{f}	85.61^{e}	13.90^{g}	14.56^{de}
		4	40.57^{c-f}	42.35^{a-d}	83.28^{ef}	86.62^{de}	14.47^{f}	15.35^{cd}
75%	Without	0	39.70^{gh}	41.56^{a-f}	73.34^{i}	76.12^{h}	12.73^{i}	13.45^{fgh}
		2	40.30^{efg}	42.00^{a-f}	77.75^{g}	80.72^{f}	13.28^{h}	13.91^{efg}
		4	40.42^{def}	42.31^{a-e}	82.04^{f}	85.24^{e}	13.40^{h}	14.09^{ef}
	With	0	41.07^{bc}	42.81^{a-d}	89.99^{bc}	93.68^{b}	15.42^{c}	16.16^{c}
		2	41.88^{a}	43.37^{ab}	95.11^{a}	98.75^{a}	17.69^{a}	18.58^{a}
		4	41.96^{a}	43.61^{a}	95.15^{a}	99.22^{a}	17.75^{a}	18.63^{a}
100%	Without	0	40.85^{b-e}	42.53^{a-d}	84.61^{e}	87.99^{d}	14.70^{ef}	15.39^{cd}
		2	40.90^{b-e}	42.55^{a-d}	87.18^{d}	90.45^{c}	14.77^{e}	15.54^{c}
		4	40.98^{bc}	42.59^{a-d}	88.72^{c}	92.35^{b}	15.07^{d}	15.85^{c}
	With	0	41.19^{bd}	43.03^{abc}	90.20^{b}	93.87^{b}	16.46^{b}	17.22^{b}
		2	42.11^{a}	43.60^{a}	95.40^{a}	99.25^{a}	17.82^{a}	18.83^{a}
		4	42.12^{a}	43.70^{a}	95.65^{a}	99.27^{a}	17.91^{a}	18.73^{a}
$LSD_{0.05}$			**0.61**	**3.15**	**1.43**	**1.71**	**0.26**	**0.86**

* The mean values with the same letters do not differ significantly at 0.05 level.

Through its fundamental roles as an energy source in plants, phosphorus affects nodule growth. Phosphorus is essential for promoting root and tip growth in plants, reducing the time it takes for growing nodules to be active, and benefiting the host legume. Phosphorus enhances both the quantity and size of nodules, as well as the nitrogen assimilation per unit weight of nodules. This results in an increase in the percentage and total amount of nitrogen in the collected portion of the host legume, while also improving the density of Rhizobium bacteria in the soil around the root **(Bashir *et al*., 2011)**. Phosphorus facilitates the catalysis of stress in the symbiotic relationship between legume plants and root bacteria **(Tsvetkova *et al*., 2003)**.

Emam *et al.*, (2018) concluded that adequate phosphorus enhances physiological processes and promotes dry matter accumulation in both roots and shoots. The inadequate supply of phosphorus resulted in reduced water uptake by the root system, thereby slowing plant growth as observed in the current study at 25, 50% and control (without fertilizers). Phosphorus plays a critical role in promoting root growth, thereby enhancing crops' capacity for phosphate acquisition. The application of phosphorus in green beans positively influences root proliferation, thereby improving soil water and nutrient uptake (**Haugen and Bennink, 2003**).

According to **Arjumand *et al.* (2013**), applying phosphorous fertilizer to snap beans increased phosphorous mobilization and photosynthetic activity, which in turn raised plant height, fresh and dry weights. A lack of nutrients was the cause of the control treatment's poor snap bean production and growth. By encouraging effective energy transfer during photosynthesis, phosphorus strongly improves the general health and growth. The prior findings indicated that phosphorus is essential in substantial amounts in shoot tips, where metabolic activity is elevated and cell division occurs rapidly (**Sakara and Baddour, 2020)**. Therefore, this suggests that the snap bean plants utilized the mineral phosphorus applied judiciously in their growth and development processes. Phosphorus plays a beneficial role in the growth of the root system, contributes to epidermal osmotic adjustment, and is an essential component in numerous enzymatic reactions that depend on phosphorylation. The favorable effect of high P level on plant vegetative growth parameters agrees with **El-Ghany *et al.* (2021); Obssi *et al.* (2022); Khaleeq *et al.* (2023); Aram *et al.* (2024).**

The stimulatory impact of AMF inoculation on snap bean growth likely stems from the influence of AM fungus on enhancing soil structure (**Miller and Jastrow 2000**), water absorption (**Augé 2001; Ruiz-Lozano, 2003**), and the uptake of various nutrients, particularly under improved P nutrition (**Rouphael *et al.* 2010**). Furthermore, the stimulatory effects of mycorrhiza were observed to be associated with an increase in the levels of endogenous hormones, specifically gibberellins and indole acetic acid (**Abd Allah *et al.* 2015**), which are recognized for their role in promoting the growth of plant organs. In conformity with the current result, the same results were obtained by **Morsy and Mehanna (2022**), **Beltayef *et al.* (2023),** and **Sadeghi and Aboutalebian (2024).**

Regarding the foliar application of seaweed extract, the results obtained indicated that, in comparison to the control, the foliar application of seaweed extract at 2 or 4 g/l boosted plant growth metrics. The potential of seaweed extract to enhance growth may be linked to the presence of macro elements and growth regulators. Seaweed extract has been recognized for its ability to enhance the growth of fruits, vegetables, and various crops, as it is reported to contain plant growth regulators like IBA, IAA, cytokinins, gibberellins, betaines, and macronutrients (**Amin *et al.*, 2020**).

Yield and its components

Effect of individual application

The effects of P-fertilization rates (0, 25, 50, 75 and 100% RD) and foliar spray of seaweed extract (0, 2 and 4 g/l), in the presence or absence of AMF, and their interactions on the snap bean yield and its components

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include pod length (cm), pod diameter (mm), number of pods per plant, weight of pods per plant, and pods yield (ton/fad), compared to untreated plants, are presented in Tables 5, 6, 7, 8 and 9 across of 2022 and 2023 seasons.

The data presented in Table (8) show the effect of different phosphorus (P) fertilization rates on snap bean yield and its components. The results clearly indicate that increasing P applications significantly enhanced all the studied yield traits. The mean values for pod length (cm), pod diameter (mm), number of pods per plant, weight of pods per plant, and total pod yield (ton/fad.) increased progressively with higher P-fertilization levels. The highest mean values for these traits were recorded in plants receiving 100% of the recommended P dose, exceeding the control by 30.18–29.92%, 50.68–51.21%, 44.73–48.77%, 83.59–84.46%, and 83.46–84.67% during the 2022 and 2023 seasons, respectively. These were followed by plants treated with 75% P-fertilization, which surpassed the control by 26.32–26.31%, 43.47–44.13%, 39.78–42.61%, 70.12–70.59%, and 70.37–70.56% for the same traits, respectively, across both experimental seasons.

The data presented in Table (8) indicate that the mean values of all yield traits were consistently higher in AMF-inoculated snap bean plants compared to uninoculated ones. The percentage increases in AMF-inoculated plants during the two growing seasons were 7.57–7.80% for pod length (cm), 9.95–9.77% for pod diameter (mm), 8.34–10.99% for the number of pods per plant, 16.14–16.25% for pod weight per plant, and 16.12–16.40% for total pod yield (ton/fad), respectively.

The data tabulated in Table (8) show that foliar application of seaweed extract significantly increased the mean values of all measured traits in snap bean plants compared to untreated controls. Application at 4 g/l resulted in the highest mean values for the evaluated parameters during both growing seasons, followed by the 2 g/l treatment. However, the difference between the two concentrations was not statistically significant.

Effect of dual application

Table (9) presents significant increases in all studied parameters for treated plants with P-fertilizer at concentrations of 0, 25, 50, 75, and 100%, regardless of the presence or absence of AMF. In this context, the maximum values for pod length (cm), pod diameter (mm), number of pods per plant, weight of pods per plant, and pod yield (ton/fad) of snap bean plants were observed in those treated with 100% recommended dose of phosphorus fertilizer in the presence of arbuscular mycorrhizal fungi (15.23-15.53cm, 8.01-8.41 mm, 12.11-12.78, 92.02-93.88 g and 7.98-8.14 ton.fad^{-1}), respectively for pod length, pod diameter, number of pods per plant, weight of pods per plant, and pod yield showing no significant difference compared to plants treated with 75% RD of phosphorus fertilizer in the presence of AMF in pod length and number of pods. The lowest values were recorded in the untreated plants. The data analyzed revealed an interaction effect between P-fertilizer rates and varying levels of seaweed extract foliar application on pod length (cm), pod diameter (mm), number of pods per plant, weight of pods per plant, and pod yield (ton/fad) in snap bean plants.

All specified parameters were significantly influenced by the treatments applied. Table (10) demonstrates that yield parameters were significantly enhanced at both SWE levels (2 or 4 g/l) across all P-fertilizer rates. The plants treated with P-fertilizers at 100% RD and 4 g/l SWE foliar application exhibited the highest mean values for yield parameters, showing no significant difference compared to those treated with the same rate of P-fertilizer and 2 g/l SWE, except for pod weight and total yield during the 2022 and 2023 seasons.

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Table 8: Effect of individual treatment of P-fertilization rate and foliar application with seaweed extract in the presence or absence of AMF on snap bean yield and its components during 2022 and 2023 seasons.

Treatments	Pod length (cm)		Pod diameter		No. of pods/plant		Weight of Pods g/plant		Green pods yield ton/fad	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Phosphorus fertilization (%)										
0	11.40e	11.63e	5.13e	5.37e	8.07d	8.12e	46.76e	47.43e	2.09e	2.12e
25	12.49d	12.72d	6.29d	6.61d	9.72c	9.58d	63.15d	64.05d	2.82d	2.86d
50	13.33c	13.65c	6.70c	7.04c	10.45b	10.48c	69.08c	70.16c	3.09c	3.14c
75	14.40b	14.69b	7.36b	7.74b	11.28a	11.58b	79.55b	80.91b	3.55b	3.62b
100	14.84a	15.11a	7.73a	8.12a	11.68a	12.08a	85.73a	87.49a	3.83a	3.91a
AMF- inoculation										
Without	12.81b	13.05b	6.33b	6.65b	9.83b	9.83b	63.71b	64.75b	2.85b	2.89b
With	13.78a	14.07a	6.96a	7.30a	10.65a	10.91a	73.99a	75.27a	3.31a	3.36a
Seaweed extract (g/l)										
0	13.01b	13.28b	6.47c	6.79c	9.98b	10.08b	65.83c	67.00c	2.94c	2.99c
2	13.36a	13.64a	6.68b	7.02b	10.32a	10.42a	69.46b	70.65b	3.10b	3.16b
4	13.51a	13.77a	6.78a	7.12a	10.42a	10.61a	71.26a	72.38a	3.18a	3.23a

* The mean values with the same letters, within each group, do not differ significantly at 0.05 lev

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Table 9: Effect of interaction treatment of P-fertilization rate and presence or absence of AMF on snap bean yield and its components during 2022 and 2023 seasons.

Treatments		Pod length (cm)		Pod diameter (mm)		No. of pods/plant		Weight of Pods (g/plant)		Green pods yield (ton/fad)	
		2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
P_2O_5	AMF										
0%	Without	11.18^{f}	11.38^{h}	4.83^{j}	5.08^{j}	7.89^{g}	7.89^{g}	43.54^{j}	44.16^{i}	1.95^{j}	1.97^{i}
	With	11.63^{ef}	11.88^{g}	5.42^{i}	5.67^{i}	8.33^{g}	8.44^{f}	49.99^{i}	50.71^{h}	2.23^{i}	2.27^{h}
25%	Without	12.03^{e}	12.24^{f}	6.11^{h}	6.42^{h}	9.33^{f}	9.11^{e}	59.53^{h}	60.33^{g}	2.66^{h}	2.70^{g}
	With	12.96^{d}	13.20^{e}	6.47^{f}	6.79^{f}	10.22^{def}	110.^{1d1}	66.76^{f}	67.77^{f}	2.98^{f}	3.03^{f}
50%	Without	12.71^{d}	12.96^{e}	6.35^{g}	6.66^{g}	10.00^{ef}	9.89^{d}	65.85^{g}	66.85^{f}	2.94^{g}	2.99^{f}
	With	13.94^{bc}	14.34^{c}	7.05^{d}	7.42^{d}	10.89^{cde}	11.11^{c}	72.30^{d}	73.48^{d}	3.23^{d}	3.28^{d}
75%	Without	13.66^{c}	13.97^{d}	6.90^{e}	7.25^{e}	11.00^{bcd}	11.11^{c}	70.20^{e}	71.33^{e}	3.14^{e}	3.19^{e}
	With	15.14^{a}	15.42^{a}	7.83^{b}	8.22^{b}	11.89^{ab}	12.56^{a}	88.89^{b}	90.49^{b}	3.97^{d}	4.04^{b}
100%	Without	14.45^{b}	14.70^{b}	7.45^{c}	7.83^{c}	11.44^{abc}	11.78^{b}	79.43^{c}	81.09^{c}	3.55^{c}	3.62^{c}
	With	15.23^{a}	15.53^{a}	8.01^{a}	8.41^{a}	12.11^{a}	12.78^{a}	92.02^{a}	93.88^{a}	4.11^{a}	4.20^{a}

* The mean values with the same letters do not differ significantly at 0.05 level.

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Table 10: Effect of interaction treatment of P-fertilization rate and foliar application of seaweed extract on snap bean yield and its components during 2022 and 2023 seasons.

Treatments		Pod length (cm)		Pod diameter (mm)		No. of pods/plant		Weight of Pods (g/plant)		Green pods yield (ton/fad)	
		2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
P_2O_5	**SWE (g/l)**										
0%	**0**	7.85^{i}	7.85^{i}	4.94^{k}	5.16^{l}	7.85^{h}	7.85^{h}	43.96^{m}	44.62^{m}	1.96^{m}	1.99^{m}
	2	11.40^{i}	11.66^{i}	5.14^{j}	5.40^{k}	8.15^{h}	8.10^{h}	46.28^{l}	46.90^{l}	2.07^{l}	2.10^{l}
	4	11.56^{i}	11.79^{i}	5.30^{i}	5.56^{j}	8.20^{h}	8.40^{h}	50.04^{k}	50.79^{k}	2.24^{k}	2.27^{k}
25%	**0**	12.19^{h}	12.41^{h}	6.17^{h}	6.47^{i}	9.35^{g}	9.25^{g}	59.91^{j}	60.75^{j}	2.68^{j}	2.71^{j}
	2	12.57^{g}	12.81^{gh}	6.30^{g}	6.62^{h}	9.85^{fg}	9.70^{f}	64.64^{i}	65.66^{i}	2.89^{i}	2.93^{i}
	4	12.72^{fg}	12.93^{g}	6.41^{f}	6.73^{g}	9.95^{efg}	9.80^{f}	64.88^{i}	65.75^{i}	2.90^{i}	2.94^{i}
50%	**0**	12.96^{f}	13.31^{fg}	6.51^{f}	6.85^{f}	10.15^{def}	10.15^{ef}	66.23^{h}	67.33^{h}	2.96^{g}	3.01^{h}
	2	13.44^{e}	13.73^{ef}	6.76^{e}	7.09^{e}	10.50^{de}	10.55^{de}	69.35^{g}	70.41^{g}	3.10^{h}	3.15^{g}
	4	13.58^{e}	13.91^{de}	6.83^{e}	7.18^{e}	10.70^{cd}	10.75^{d}	71.65^{f}	72.75^{f}	3.20^{f}	3.25^{f}
75%	**0**	14.07^{d}	14.38^{cd}	7.19^{d}	7.57^{d}	11.05^{bc}	11.30^{c}	76.19^{e}	77.59^{e}	3.40^{e}	3.47^{e}
	2	14.49^{c}	14.80^{bc}	7.40^{c}	7.77^{c}	11.35^{ab}	11.65^{bc}	80.91^{d}	82.44^{d}	3.62^{d}	3.68^{d}
	4	14.64^{bc}	14.91^{ab}	7.50^{b}	7.87^{b}	11.45^{ab}	11.80^{ab}	81.54^{d}	82.70^{d}	3.64^{d}	3.70^{d}
100%	**0**	14.59^{bc}	14.84^{abc}	7.55^{b}	7.90^{b}	11.50^{ab}	11.85^{abc}	82.87^{c}	84.73^{c}	3.70^{c}	3.79^{c}
	2	14.91^{ab}	15.19^{ab}	7.78^{a}	8.19^{a}	11.75^{a}	12.10^{ab}	86.12^{b}	87.85^{b}	3.85^{b}	3.93^{b}
	4	15.03^{a}	15.31^{a}	7.87^{a}	8.26^{a}	11.80^{a}	12.30^{a}	88.18^{a}	89.89^{a}	3.94^{a}	4.02^{a}

* The mean values with the same letters do not differ significantly at 0.05 level.

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Table 11: Effect of interaction of foliar application of seaweed extract in the presence or absence of AMF on snap bean yield and its components during 2022 and 2023 seasons.

Treatments		**Pod length (cm)**		**Pod diameter (mm)**		**No. of pods/plant**		**Weight of Pods (g/plant)**		**Green pods yield (ton/fad)**	
		2022	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
AMF	**SWE (g/l)**										
Without	**0**	12.60^{d}	12.84^{d}	6.21^{f}	6.52^{f}	9.60^{d}	9.54^{d}	61.38^{f}	62.38^{f}	2.74^{f}	2.79^{f}
	2	12.82^{c}	13.06^{cd}	6.34^{e}	6.66^{e}	9.88^{cd}	9.86^{cd}	63.93^{e}	64.94^{e}	2.86^{e}	2.90^{e}
	4	13.00^{c}	13.24^{c}	6.43^{d}	6.76^{d}	10.00^{bc}	10.10^{c}	65.82^{d}	66.93^{d}	2.94^{d}	2.99^{d}
With AMF	**0**	13.43^{b}	13.72^{b}	6.73^{c}	7.05^{c}	10.36^{b}	10.62^{b}	70.28^{c}	71.62^{c}	3.14^{c}	3.20^{c}
	2	13.91^{a}	14.21^{a}	7.01^{b}	7.37^{b}	10.76^{a}	10.98^{a}	74.99^{b}	76.36^{b}	3.35^{b}	3.41^{b}
	4	14.01^{a}	14.29^{a}	7.13^{a}	7.48^{a}	10.84^{a}	11.12^{a}	76.69^{a}	77.82^{a}	3.43^{a}	3.48^{a}
$LSD_{0.05}$		**0.22**	**0.32**	**0.07**	**0.06**	**0.37**	**0.34**	**0.44**	**0.59**	**0.59**	**0.04**

* The mean values with the same letters do not differ significantly at 0.05 level.

The interaction effect of seaweed extract, with and without arbuscular mycorrhizal fungi (AMF), on the yield and its components in snap bean plants presented in Table (11) indicate that all studied traits exhibited significant increases in response to all treatments across the two growing seasons when compared to the control treatment. The highest mean values were observed with foliar application of 4 g/l SWE, followed by 2 g/l, showing no significant differences in pod length, diameter, and number, all in the presence of AMF. The same trend was observed during two seasons.

Effect of triple application

The interaction effects of the studied treatments on snap bean yield and its components are presented in Table (12). A significant positive impact was observed on all measured traits. The highest mean values were obtained from the combination of 100% of the recommended P-fertilization dose with either 2 g/l or 4 g/l seaweed extract applied as a foliar spray in the presence of AMF, with no significant differences between these two combinations. These were followed by treatments of 75% RD P-fertilization combined with 4 g/l or 2 g/l seaweed extract, also applied with AMF. For most traits, no significant differences were detected between these treatments, but they all outperformed the control plants. The remaining treatments produced intermediate values across the two seasons.

The increase in the number of pods and pod yield per plant and faddan resulting from elevated phosphorus (P) fertilization up to an optimal level may enhance nodule formation, fruiting, protein synthesis, and seed development. The improvement in snap bean yield following P fertilizer application can be attributed to adequate phosphorus supply, which likely promotes vegetative growth characters. This, in turn, increases the photosynthetic surface and the number of pods per plant, reflecting a strong correlation with dry matter accumulation and yield (**Zebire and Gelgelo, 2019**).

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Table 12: Interaction effect between P-fertilization rate and foliar application with seaweed extract in the presence or absence of AMF on snap bean yield and its components during 2022 and 2023 seasons.

Treatments			Pod length cm		Pod diameter (mm)		No. of pods/plant		Weight of Pods g/plant		Green pods yield	
			2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
P_2O_5(%)	AMF	SWE (g/l)										
0	Without	0	11.03^{w}	11.22^{p}	4.73^{y}	4.98^{u}	7.60^{lm}	7.50^{jk}	42.38^{t}	42.97^{r}	1.89^{t}	1.92^{r}
		2	11.16^{vw}	11.39^{op}	4.83^{xy}	5.06^{tu}	7.90^{m}	7.80^{k}	42.94^{t}	43.50^{r}	1.92^{t}	1.94^{r}
		4	11.34^{u-w}	11.54^{op}	4.94^{x}	5.18^{t}	7.90^{lm}	8.20^{jk}	45.30^{s}	46.02^{q}	2.02^{s}	2.06^{q}
	With	0	11.47^{t-w}	11.69^{n-p}	5.15^{w}	5.33^{s}	8.10^{lm}	8.20^{jk}	45.55^{s}	46.26^{q}	2.04^{s}	2.07^{q}
		2	11.63^{s-w}	11.93^{m-o}	5.46^{v}	5.73^{r}	8.40^{j-l}	8.40^{ij}	49.62^{r}	50.29^{p}	2.22^{r}	2.25^{p}
		4	11.78^{r-u}	12.04^{l-o}	5.66^{u}	5.94^{q}	8.50^{k-m}	8.60^{ij}	54.78^{q}	55.57^{o}	2.45^{q}	2.48^{o}
25	Without	0	11.88^{q-t}	12.09^{l-o}	6.04^{t}	6.33^{p}	8.90^{i-k}	8.70^{ij}	56.24^{p}	57.03^{n}	2.51^{p}	2.55^{n}
		2	12.02^{p-s}	12.25^{l-n}	6.10st	6.42^{op}	9.40^{g-i}	9.20^{hi}	61.16^{o}	61.99^{m}	2.73^{o}	2.77^{m}
		4	12.19^{p-r}	12.36^{k-n}	6.20^{rs}	6.51^{no}	9.50^{h-j}	9.30^{hi}	61.20^{o}	61.97^{m}	2.74^{o}	2.77^{m}
	With	0	12.50^{n-p}	12.72^{i-l}	6.30^{qr}	6.61^{mn}	9.80^{f-h}	9.80^{gh}	63.58^{n}	64.47^{l}	2.84^{n}	2.88^{l}
		2	13.13^{k-m}	13.37^{f-i}	6.49^{op}	6.82^{kl}	10.30^{e-g}	10.20^{fg}	68.13^{l}	69.33^{j}	3.04^{l}	3.10^{j}
		4	13.25^{j-m}	13.50^{e-h}	6.62^{no}	6.94^{jk}	10.40^{e-g}	10.30^{fg}	68.57^{l}	69.53^{j}	3.06^{l}	3.11^{j}
50	Without	0	12.36^{o-q}	12.61^{j-m}	6.22^{rs}	6.53^{no}	9.70^{g-i}	9.50^{hi}	63.46^{o}	64.47^{l}	2.84^{n}	2.88^{l}
		2	12.81^{mno}	12.97^{h-k}	6.38^{pq}	6.71^{lm}	10.00^{f-h}	9.90^{gh}	65.96^{m}	66.95^{k}	2.95^{m}	2.99^{k}
		4	12.98^{l-n}	13.30^{g-j}	6.44^{pq}	6.74^{lm}	10.20^{e-g}	10.10^{fg}	68.13^{l}	69.13^{j}	3.04^{l}	3.09^{j}
		0	13.56^{i-k}	14.02^{def}	6.80^{lm}	7.17^{hi}	10.60^{d-f}	10.80^{ef}	69.00^{l}	70.19^{j}	3.08^{l}	3.14^{j}

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Treatments			Pod length cm		Pod diameter (mm)		No. of pods/plant		Weight of Pods g/plant		Green pods yield	
			2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
	With	2	14.08^{f-h}	14.49^{cd}	7.14^{ij}	7.47^{g}	11.00^{c-e}	11.20^{ef}	72.73^{i}	73.87^{h}	3.25^{i}	3.30^{h}
		4	14.19^{e-g}	14.52^{cd}	7.22^{hi}	7.62^{f}	11.20^{c-e}	11.40^{de}	75.18^{h}	76.38^{g}	3.36^{h}	3.41^{g}
75	Without	0	13.41^{i-l}	13.75^{efg}	6.71^{mn}	7.07^{ij}	10.50^{d-f}	10.60^{ef}	68.51^{l}	69.60^{j}	3.06^{l}	3.11^{j}
		2	13.67^{h-j}	14.00^{d-g}	6.93^{kl}	7.27^{h}	10.70^{c-e}	10.80^{ef}	70.45^{k}	71.58^{i}	3.15^{k}	3.20^{i}
		4	13.90^{g-i}	14.15^{de}	7.05^{jk}	7.41^{g}	10.90^{b-d}	11.00^{de}	71.65^{j}	72.80^{hi}	3.20^{j}	3.25^{c}
	With	0	14.73^{cd}	15.00^{bc}	7.66^{de}	8.06^{cd}	11.60^{abc}	12.00^{b-d}	83.88^{d}	85.58^{d}	3.75^{d}	3.82^{f}
		2	15.31^{ab}	15.59^{ab}	7.87^{bc}	8.27^{b}	12.00^{ab}	12.50^{ab}	91.37^{b}	93.30^{b}	4.08^{b}	4.17^{e}
		4	15.37^{a}	15.66^{ab}	7.95^{b}	8.33^{b}	12.00^{ab}	12.60^{a}	91.42^{b}	92.60^{bc}	4.09^{b}	4.14^{d}
100	Without	0	14.31^{d-g}	14.53^{cd}	7.34^{gh}	7.70^{f}	11.30^{b-d}	11.40^{c-e}	76.32^{g}	77.84^{f}	3.41^{g}	3.48^{hi}
		2	14.44^{c-f}	14.70^{cd}	7.45^{fg}	7.84^{e}	11.40^{b-d}	11.60^{c-e}	79.13^{f}	80.68^{e}	3.54^{f}	3.61^{d}
		4	14.61^{c-e}	14.87^{c}	7.54^{ef}	7.94^{de}	11.50^{a-c}	11.90^{b-d}	82.84^{e}	84.76^{d}	3.70^{e}	3.79^{b}
	With	0	14.87^{bc}	15.16^{a-c}	7.75^{cd}	8.10^{c}	11.70^{abc}	12.30^{abc}	89.42^{c}	91.62^{c}	4.00^{c}	4.09^{c}
		2	15.39^{a}	15.69^{ab}	8.10^{a}	8.54^{a}	12.10^{a}	12.60^{a}	93.11^{a}	95.02^{a}	4.16^{a}	4.25^{a}
		4	15.45^{a}	15.74^{a}	8.19^{a}	8.57^{a}	12.10^{a}	12.70^{a}	93.53^{a}	95.02^{a}	4.18^{a}	4.25^{a}

* The mean values with the same letters do not differ significantly at 0.05 level.

The beneficial effects of P fertilization on snap bean production can be linked to phosphorus's ability to support both vegetative and reproductive growth phases, thereby improving photosynthetic efficiency. Additionally, phosphorus plays a vital physiological role in stimulating meristematic activity in plant tissues, which promotes growth, and serves as a component of enzyme systems essential for synthesizing various organic compounds from carbohydrates (**Sakara and Baddour, 2020).** The positive impact of high P levels on snap bean productivity aligns with findings reported by **Negash *et a*l. (2018), Awaad *et al.* (2020), Obssi *et al*. (2022),** and **Olika and Alemu (2024).**

The study by **Shabana *et al.* (2020)** on *Phaseolus vulgaris* L. reported that inoculation with vesicular arbuscular mycorrhizal fungi (AMF) significantly improved yield components, including the number of pods per plant, 100-seed weight, number of seeds per pod, seed yield per faddan, and harvest index percentage in the dry bean cultivar Nebraska, compared to non-inoculated plants. Similarly, **Massa *et al.* (2020**) found that AMF inoculation enhanced yield traits such as pod and seed number and weight in common bean relative to uninoculated controls. These findings are consistent with the results of the present study.

Beckett *et al.* (1994) identified two main mechanisms by which seaweed extract enhances yield in bean plants. First, it increases the source capability of leaves, thereby boosting the supply of assimilates necessary for pod filling. This effect may occur through the enlargement of leaf area or improved photosynthetic efficiency. Second, the application of seaweed extract enhances the sink strength of the beans by potentially increasing cotyledon cell numbers, which contributes to greater final bean mass. Seaweed extract contains various bioactive components such as cytokinins, vitamins, auxins, amino acids, as well as macro- and micronutrients, all of which influence cellular metabolism in treated plants and promote growth and yield in common bean (**Zewail, 2014**). The observed increases in snap bean yield and its parameters following foliar application of seaweed extract can be attributed to its beneficial effects on plant growth and fruit development.

CONCLUSION

The present study demonstrates that the combined application of phosphorus fertilization and seaweed extract, together with arbuscular mycorrhizal fungi, significantly enhanced both the vegetative growth and yield and its components characters. Overall, the treatments exerted a positive effect in most evaluated parameters, indicating their potential as effective practices for improving snap bean production. Notably, the combination of 75% of the recommended P-fertilization applied to the soil with 2 or 4 g/l seaweed extract as a foliar application in the presence of AMF was identified as the most economical and effective treatment for maximizing snap bean yield under the tested conditions.

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إمكانية خفض معدلات التسميد الفوسفاتي الكيميائي باستخدام فطريات الميكوريزا والرش الورقي بمستخلص الأعشاب البحرية وتأثيره على نمو وإنتاجية الفاصوليا الخضراء

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أجريت تجربتان حقليتان خلال موسمين متتاليين ٢٠٢٢ و٢٠٢٣ في مزرعة خاصة تقع في حوش عيسى، محافظة البحيرة. لدراسة تأثير معدلات مختلفة من التسميد الفوسفاتي والرش الورقي بمستخلص الأعشاب البحرية في وجود أو غياب الميكوريزا على نبات الفاصوليا الخضراء صنف فلانتينو. تم استخدام تصميم القطاعات العشوائية الكاملة بنظام القطع المنشقة لمرتين حيث وضعت المعدلات المختلفة من التسميد الفوسفاتي (٠، ٢٥، ٥٠، ٧٥ و١٠٠٪ من الموصي به) كقطع رئيسية، في وجود وعدم وجود الميكوريزا كقطع منشقة والرش الورقي بمستويات مختلفة من مستخلص الأعشاب البحرية (٠، ٢، ٤ جم/لتر) كقطع تحت منشقة فى ثلاث مكررات. سجلت قياسات النمو الخضري (طول النبات، الوزن الطازج والجاف)، المحصول ومكوناته (طول القرون، قطر القرون، عدد القرون/نبات، وزن القرون للنبات، محصول القرون للفدان) حيث أظهرت النتائج تأثير معنوي لجميع المعاملات المدروسة على جميع الصفات المذكورة خلال كلا الموسمين. كما أوضحت النتائج أن استخدام ٧٥٪ من الموصى به تسميد فوسفاتى، في وجود الميكوريزا بالإضافة إلى الرش الورقي بمستخلص الأعشاب البحرية سواء بمعدل ٤ أو ٢ جم/لتر هي المعاملة الأكثر ملائمة في الحد من استخدام الأسمدة الفوسفاتية الكيميائية مما يقلل من مخاطرها البيئية والحصول على أفضل صفات جوده للفاصوليا الخضراء آمنه للاستهلاك الآدمي.

كلمات مفتاحيه: تسميد فوسفاتى، ميكوريزا، مستخلص أعشاب بحرية، فاصوليا خضراء.