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Research Article

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Under Long-Term Condition, Role of Increasing Doses Phosphorus Application on Soybean (*Glycine max* L.) Some Nutrient Uptake and Yield

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ABSTRACT
Soybeans, as an industrial plant, are used in many industries. Since soybeans fix nitrogen through the rhizobium bacteria, P fertilization is one of the biggest requested fertilizers in their production. In this context, under long-term experimental conditions, the aim is to investigate the effect of increasing doses of P application on soybean yield and nutrient uptake. The hypothesis is that optimum P fertilizer doses increase soybean yield and P uptake.
A field experiment was established in 1998 on the soil Arık soil series. Four doses of P fertilizers were applied, such as 0, 50, 100, and 200 kg P_2O_5 ha^{-1} with three replications before each cultivation term. Arısoy soybean (*Glycine max* L.) species seeds were sown in May 2024 and harvested in November 2024. At harvest, root, shoot dry weights, and yield were determined. Plant mineral nutrients (K, P and Zn) concentrations were analyzed by ICP-OES. ANOVA statistical analysis was realized by the JMP 8-pack program, and the less significant difference (LSD) test was carried out. Research results have shown that there is no significant difference in root dry matter and yield, but there is a significant difference in shoot dry matter yield. Especially when soybean grain yield was examined yield increased due to increasing doses from P0 to P200 (1596, 2390, 2431 and 2512 kg ha^{-1}) fertilization, respectively. Furthermore, increasing doses of P fertilization statistically increased grain P concentration in a linear manner. Overall, for soybeans, 100 kg P_2O_5 ha^{-1} phosphorus fertilization is given an optimum dose for optimum growth. It was determined that the 100 kg P_2O_5 ha^{-1} application is the optimum application in soybean cultivation growth and nutrient uptake under long-term field experiments.
Keywords: Long-term phosphorus, Soybean, Yield and Nutrient uptake

INTRODUCTION

Due to the increasing world population, food supply and food security are also jeopardized. Agricultural products, which are processed in many fields, especially in industry, have recently been of great importance. Soybean, one of these products, has many industries such as animal feed, oil, protein, and milk (Ali, 2010). Soybean is the first source of vegetable oils and important protein animal feed on the earth. Soybean seed contains 38-42% protein and 18-22% oil (Wang et al., 2019). Soybean is utilized in many different ways in the industry. Soybean is used in confectionery, putty compositions used in construction, fungicides and pesticides, antibiotics, diesel fuel and industrial and pharmaceutical products to provide raw materials for many other industries. It is also used as a printing ink. For animal nutritionists, Soybeans are very important in terms of amino acids and digestibility (Ravindran et al., 2014). When ground soybean is mixed with other grains such as maize, the protein content of this mixture is higher than when the nutrient is used alone.

In addition, soybean, which is a legume, is an important rotation plant that increases the fertility of the soil by providing organic matter and nitrogen to the soil. Soybeans fixed N thorough rhizobium bacteria (*Brady rhizobium japonicum*) in the roots. Soybean fixes approximately 50-150 kg N per hectare (Özer et al., 2021). In the production of nitrogen-fixing soybean crops, the element with the second critical role is phosphorus (P). P fertilization has an important place in soybean cultivation (Khan et al., 2020).

Fertilization is a parameter affecting yield and quality in crop production (Kılıç and Korkmaz, 2012). P is the second most consumed element in terms of quantity. P deficiency in plant production does not occur, while its excess causes eutrophication. Phosphorus elements under soils with high lime content and pH combined with calcium make Ca-P which reduces the P availability in semi-arid region soils. These compounds are not utilized by plants. P element by plants available forms are HPO_4^-, and $H_2PO_4^-$ (Işık et al., 2021). Phosphorus photosynthesis in plants is involved in many metabolic activities such as energy, phospholipids and nucleic acids (Vance et al., 2003). Apatite rock, which is the source of the P element, will be depleted in the next 50-150 years.

In this context, the research of our study the question of whether the effect of continuous (graded) P dose application on plant growth is economical or not is not well known. Increasing doses of P application to Soybean plants under long-term field conditions development, yield and nutrient uptake, and determining the optimum level of P fertilization is important for the farmer and the country's soil and agriculture in many ways.

This study aimed to investigate the effect of increasing doses of P application on Soybean to investigate the effect on yield, nutrient uptake and P utilization efficiency in common beans. The optimum P dose under increasing doses of phosphorus fertilizer application under long-term experimental conditions; increases the yield, nutrient uptake and P utilization efficiency of the Soybean plant.

MATERIALS AND METHODS

A field experiment was established in 1998 on the soil Arık series, which is classified as typical Haploxererts, as a randomized block design in the University of Cukurova, Department of Soil Science and Plant Nutrition Research Center in the Mediterranean region Adana, Türkiye, Some physico-chemical properties of Arık soil series are shown in Table 1. Four doses of P fertilizers were applied, such as 0, 50, 100, and 200 kg P_2O_5 ha^{-1} (as P0, P50, P100 and P200), with three replications before each cultivation term. Arısoy soybean (*Glycine max* L.) species seeds were sown in May 2024 and harvested in November 2024.

Table 1. Some physicochemical properties of the Arık soil series (Turgut and Koca, 2019).

Soil Properties	Units	Result
pH	(sat.)	7.63
EC	(mmhos cm^{-1})	0.06
Lime	(%)	27.2
O.M.	(%)	1.17
Texture (%)	Sand	17
	Silt	28
	Clay	55
Texture Classification	-	C
P_2O_5	(kg da^{-1})	7.11

At harvest, root, shoot dry weights, and yield were determined. In addition, the yield of soybean Agronomic Efficiency (AE) was calculated according to Equal 1. Plant tissue's mineral nutrients, such as K, P and Zn concentrations were analyzed by ICP-OES. ANOVA statistical analysis was done by the JMP 8-pack program and the Less Significant Different (LSD) test was carried out.

$$AE = \frac{P0 - PF}{Fertilizer\ amount}$$

Equal 1.

P0=Without P fertilizer soybean yield
PF=With P fertilizers soybean yield

RESULTS AND DISCUSSIONS

Root Infection

The highest root infections were observed in P0-P50 treatments with 33.3% and 35.0% (Figure 1). As can be seen in Figure 1, P dose application increases did not cause a statistically significant difference in mycorrhizal root infection. However, the application of increasing P doses relatively decreased percentages of root infection on average. It is expected that the root infection rate will decrease as the P dose increases over the critical levels. Previously Savin et al. (2009) and (Akpinar and Ortas, 2023) reported that increasing P fertilization reduced mycorrhizal infection in cotton and maize plants. Moreover, Martínez-Medina et al. (2011) also, reported that reduced fertilizer dosage increases AM root colonization by *Funneliformis constrictum* or *Rhizophagus intraradices*. These studies support our research findings.

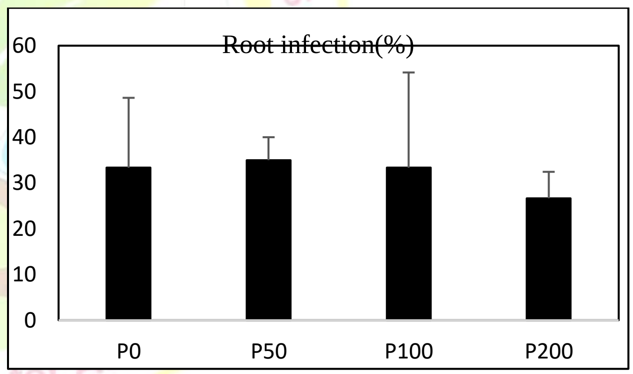

Figure 1. Effect of increasing P application on root infection.

P0 (Control), P50 (50 kg P_2O_5 ha^{-1}), P100 (100 kg P_2O_5 ha^{-1}), P200 (200 kg P_2O_5 ha^{-1}).

Dry Matter Yield

The impact of increasing doses of P application upon dry matter yield of different parts of soybean is shown in Table 2. Shoot (P<0.0019) and seed (P<0.0010) were found to be statistically significant. It is seen that increasing doses of P application increased the growth and yield of different parts of soybean (especially above-root parts and grain). It is expected that the yield of the plant will increase as phosphorus fertilization increases. For example; previously in the same field experiment area, Işık et al. (2021) investigated the effect of increasing doses of P application on maize plant nutrition, yield and P utilization efficiency. In this study, it was observed that increasing doses of P application increased maize yield.

It was observed that increasing doses of P application increased soybean yield. Similarly, Akpinar and Ortas (2023) reported that increasing doses of P application increased wheat yield in the same experimental area as well. Their studies support our research findings. In addition, Table 4 shows that there is a positive (0.922) correlation between shoot %P and seed yield. There is also a positive correlation between root %P and seed yield (0.815).

Table 2. Effect of increasing P application on root, shoot and seed DMY

Doses	Root (kg ha^{-1})	Shoot	Seed
P0	1361±804	1361±804	1361±804
P50	1906±587	1906±587	1906±587
P100	1637±339	1637±339	1637±339
P200	1754±445	1754±445	1754±445
	NS	**	***

NS (as not significant), *, ** and *** show significant levels at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$. P0 (Control), P50 (50 kg P_2O_5 ha^{-1}), P100 (100 kg P_2O_5 ha^{-1}), P200 (200 kg P_2O_5 ha^{-1}).

Nutrient Concentrations of Different Parts of Soybean

The effect of increasing doses of P application on the P, K and Zn concentrations of different parts of soybean is shown in Table 3. Phosphorus application at different doses did not create a statistically significant difference in terms of soybean plant mineral nutrient concentrations.

The effect of different phosphorus doses on the % P content of the plant was found statistically significant in seed (P<0.0050), shoot (P<0.0001) and root (P<0.0012) parts. The concentration of P in soybean tissues raised with increasing P application dosas. In general, P concentration in P0 treatments was below the critical value of 0.20% (Jones, 2012), whereas it increased with increasing P application in other treatments. A similar situation was observed in the findings of the study carried out by Akpinar and Ortas (2023) in the same research area, where increasing doses of P application increased wheat P uptake. However, there was no significant difference in the %K concentrations of different plant parts, while Zn concentration tended to decrease with increasing P dose application (Table 3). In the present work, plant parts Zn concentration seems to be higher than expected. In general, N2-fixing plants have a higher micronutrient than other plant species. Zn content of plant tissues increased with increasing P in grains, but Zn concentration in above-root axils decreased with increasing P fertilizer. The decrease may be due to the antagonistic relationship between P and Zn (Marschner, 2012). It is known that P fertilization forms a P-Zn compound with the Zn element (Schnug and De Kok, 2016). Moreover, Table 4 shows that there is a positive (0.859) correlation between shoot and root %P. In addition, there is also a positive (0.924) correlation between root and seed %P.

Table 3. Effect of increasing P application on different plant parts nutrition concentration

Doses	%K	%P	Zn (mg kg^{-1})
	Seed		
P0	0.80±0.03	0.17±0.04c	58.00±10.60
P50	0.90±0.04	0.38±0.02b	68.65±14.35
P100	0.88±0.04	0.43±0.02ba	67.45±4.75
P200	1.02±0.20	0.56±0.18a	70.90±1.7
	NS	**	*NS*
	Shoot		
P0	1.10±0.11	0.15±0.04c	64.03±5.46
P50	1.24±0.11	0.23±0.11b	65.30±7.42
P100	1.08±0.13	0.45±0.06a	54.17±2.06
P200	1.33±0.07	0.51±0.03a	62.10±13.83
	NS	***	*NS*
	Root		
P0	0.44±0.20	0.06±0.01c	11.05±0.55a
P50	0.34±0.12	0.17±0.02b	9.97±0.40b
P100	0.58±0.50	0.18±0.18a	11.35±0.15a
P200	0.44±0.11	0.16±0.09ba	9.63±0.25b
	NS	**	**

NS (as not significant), *, ** and *** show significant level at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$. P0 (Control), P50 (50 kg P_2O_5 ha^{-1}), P100 (100 kg P_2O_5 ha^{-1}), P200 (200 kg P_2O_5 ha^{-1}).

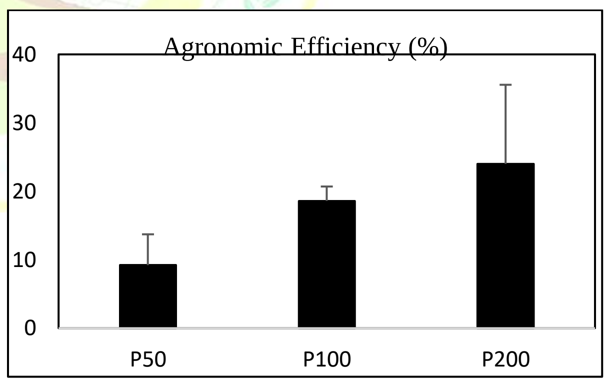

Figure 2. Effect of increasing P application on AE P50 (50 kg P_2O_5 ha^{-1}), P100 (100 kg P_2O_5 ha^{-1}), P200 (200 kg P_2O_5 ha^{-1}).

Agronomic Efficiency

The effect of increasing doses of P application on AE is shown in Figure 2. The highest AE was observed in the P100 and P200 kg ha^{-1} treatments. However, there was a statistically significant difference between the P dose application. In general, compared to control treatments, increasing P fertilizer AE is increasing.

García and Salvagiotti (2010) applied four P doses (0, 100, 200 and 400 kg ha^{-1}) to soybean and AE was calculated. AE was highest at 100 kg ha^{-1} P_2O_5 dose application and more P doses addition decreased the efficiency. Işık et al. (2021) investigated the effect of increasing doses of P application (such as 0, 50, 100 and 200 kg P_2O_5 ha^{-1}) on maize AE. It was reported that maize AE increased up to 100 kg P_2O_5 ha^{-1} and decreased at 200 kg P_2O_5 ha^{-1}. Vanlauwe et al. (2011) reported that fertilization decreased AE in his study.

Overall results shown that founded results support our hypothesis. Under field conditions, 100 kg ha^{-1} P_2O_5 dose application can be suggested for healthy soybean production.

CONCLUSIONS

Increasing doses of P fertilization increased the growth and yield of soybean plants under long-term P-applied experimental conditions. P fertilizer application also increased P uptake and AE. However, Zn concentration tended to decrease with increasing P application. The results show that 100 kg ha^{-1} P_2O_5 dose application seems to be the optimum application for soybean cultivation.

Table 4. Correlation matrix in between measured plant parameters.

	Root (kg ha^{-1})	Shoot (kg ha^{-1})	Seed (kg ha^{-1})	Root İnf.	Root K %	Root P %	Root Zn (mg kg^{-1})	Shoot K %	Shoot P %	Shoot Zn (mg kg^{-1})	Seed K %	Seed P %	Seed Zn (mg kg^{-1})
Root (kg ha^{-1})	1												
Shoot (kg ha^{-1})	0,463	1											
Seed (kg ha^{-1})	0,287	0,634	1										
Root İnf.	-0,118	-0,104	-0,141	1									
Root K %	0,056	0,161	-0,059	-0,704	1								
Root P %	0,394	0,772	0,815	-0,256	0,110	1							
Root Zn (mg kg^{-1})	-0,240	-0,434	-0,327	0,069	0,232	-0,547	1						
Shoot K %	0,330	0,410	0,457	0,053	-0,535	0,531	-0,653	1					
Shoot P %	0,245	0,710	0,922	-0,370	0,152	0,859	-0,250	0,405	1				
Shoot Zn (mg kg^{-1})	0,085	-0,128	-0,084	-0,016	-0,353	-0,351	-0,201	0,222	-0,170	1			
Seed K %	0,067	0,473	0,522	-0,025	0,014	0,686	-0,457	0,564	0,507	-0,225	1		
Seed P %	0,199	0,699	0,772	-0,219	0,089	0,924	-0,489	0,476	0,798	-0,492	0,592	1	
Seed Zn (mg kg^{-1})	0,473	0,471	0,325	-0,592	0,330	0,643	-0,263	0,381	0,572	-0,303	0,248	0,552	1

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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