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# Impact of Different Doses of Phosphorus Fertilizer Application on Wheat Yield, Soil-Plant Nutrient Uptake and Soil Carbon and Nitrogen Dynamics

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## ABSTRACT

The aim of the study was to investigate the impact of phosphorus (P) dose application effects on bread wheat (*Triticum aestivum*) yield, mineral nutrients concentration and soil C (C) and nitrogen (N) concentration. From 1998 to date, the same soil plots (200 m<sup>2</sup>) have been fertilized regularly with the same P fertilizer doses, namely 0 (P0), 50 (P50), 100 (P100), 200 (P200) kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> as triple superphosphate (TSP). For the current study, fertilization was done 1 week before seed planting in 2013. Wheat yield increased with increasing P dose applications under long-term field conditions. Compared to the control treatment, 50, 100 and 200 P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> application significantly increased wheat yield by 60%, 85% and 138%, respectively. Agronomic efficiency decreased with P-level increases. Indigenous root infection results and number of spore count decreased due to increasing P fertilizer application. With increasing fertilizer doses, soil organic C and N increased as well. It was concluded that since plants grow better with high P doses application, it may have a positive impact on organic matter (OM) remaining in the soil and increased soil C and N concentration.

## ARTICLE HISTORY

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## KEYWORDS

Phosphate fertilizer; root infection; soil organic carbon; wheat

## Introduction

P is one of the main elements affecting plant growth, and due to the limited amount of P resources on Earth, it is expected that P deficiency and thus prices will increase in the future (Chen et al. 2019; Richardson et al. 2011). P fertilizer use in crop production is the most effective way to provide P demand (Eichler-Lobermann, Köhne, and Köppen 2007) of the wheat and maize crops, which are widely cultivated in the Mediterranean region (Ortas and Bykova 2020; Ortaş and Islam 2018). In the Mediterranean climate zone, where the soils tend to have higher pH values and calcium carbonate contents, due to which difficulties of nutrient uptake can occur. Therefore, especially mineral P fertilizers are inevitably applied broadly in the region. Long-term P fertilizer application studies have shown that P is accumulated in the soil and can be turned into an unavailable fixed form (Van der Bom et al. 2019; Verloop et al. 2010). At the same time, P fertilization applied at high doses over a long time leads to the accumulation of P in the soil and as a result, rhizosphere mechanisms such as mycorrhizae are getting less active and disrupted finally, so that P uptake from the soil by plant roots and mycorrhizae is negatively affected (Ortas 2003, 2019). In today's world where fertilizer resources are limited and expensive, it is of great importance to use fertilizers at optimum doses in order to reduce the economic and environmental effects of chemical fertilizers. In addition, by knowing the

P content and natural mycorrhizal potential in the soil, a significant saving will be achieved in the amount of fertilizer to be applied to the less fertile soils.

It has been reported that the productivity of soils decreases significantly when the plant roots and soil organisms that maintain symbiotic life with mycorrhiza (Lang et al. 2022) and N fixation become inactive as a result of excessive chemical use (Carvalhais et al. 2011). Similarly, Gollner et al. (2011) and (2019) indicated that in agricultural soils, the excessive use of P fertilizers negatively affected the potential and efficiency of natural mycorrhizal spores.

Soil OM, especially organic C, has a great impact on soil fertility and quality (Fageria 2012; Yucel, Yucel, and Ortas 2020). Organic C in soil is extremely important for sustainability of productivity in agroecosystems. The effect of P fertilization on the amount of soil organic C and N over a long period of time needs to be investigated. However, the effects of excessive P fertilizer use on soil C (Ortas and Bykova 2020) and N are not fully understood. Ortas and Lal (2012) reported that increasing P application partially increased the C and N content in the soil indirectly. Under the same soil conditions, still it is a research question to understand the impact of P fertilization on organic C and N concentrations. The tested hypothesis was that P fertilization increases wheat growth and consequently increased soil organic C and N concentration.

The aim was to investigate the effects of long-term P fertilizer application on the wheat growth, yield, nutrients availability and soil C and N dynamics.

## Materials and methods

The research experiment was established in 1998 on the Arik soil series (typic Haploxererts) which is located in the Çukurova University, Faculty of Agriculture Research and Application Farm in Adana, Turkey. Different doses of P (i.e., control-0, P1–50, P2–100, and P3–200 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) in the form of Triple Superphosphate (TSP) were applied. In addition, 160 kg N ha<sup>-1</sup> as Ammonium Sulfate ((NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>) and 50 kg Potassium (K<sub>2</sub>O) ha<sup>-1</sup> as Potassium Sulfate (K<sub>2</sub>SO<sub>4</sub>) were applied. The initial properties of the soils are given in Table 1.

## Experimental design

The current experiment was conducted in 2013, Adana-99 wheat (*Triticum aestivum*) seeds were planted in 2013 and harvested in 2014. The trial was carried out in three replications based on randomized block design.

At harvest, plant shoot, root and seed dry weight were obtained per m<sup>2</sup>. Also, after harvest soil samples were taken for mineral nutrient and mycorrhizae spore analyses.

**Table 1.** Soil properties of the experimental area.

Soil properties	Unit	0-30 cm
Clay	g kg <sup>-1</sup>	580±11
Silt		270±27
Sand		150±36
Soil Organic Carbon	%	0.90±0.06
Inorganic Carbon		3.36±0.31
Total Nitrogen		0.10±0.01
CEC	Cmol <sup>+</sup> kg <sup>-1</sup>	38±1.00
pH	H <sub>2</sub> O	7.60±0.50
Salinity	%	0.04±0.02
P	mg kg <sup>-1</sup>	14.43±1.32
K		1035.1±10.1
Mycorrhiza number	10 g <sup>-1</sup> soil	63.8±11.1

Three replications average ± ds.

## Mycorrhizal colonization

After harvest, soil and plant sub samples were taken. Sub-root samples were collected for mycorrhizal colonization. Root cleaning and staining was performed as indicated by Koske and Gemma (1989), while % infection was determined according to the method specified by Giovannetti and Mosse (1980), with 40–60× magnification under a microscope. The number of mycorrhiza spores was determined according to the wet screening method of Gerdermann and Nicolson (1963).

## Nutrient analysis

The N and C concentrations in soil were determined with the Fisher CN-2000 device, according to the Dumas dry combustion method (Grant et al. 2001). Plant available P in soil samples was determined according to Olsen et al. (1954), i.e., with 0.5 Normal (N) sodium bicarbonate ( $\text{NaHCO}_3$ ) extraction. Diethylene triamine penta acetic acid (DTPA) extractable Iron (Fe), Manganese (Mn), Zinc (Zn) and Copper (Cu) concentrations in the soil were determined by inductively coupled plasma (ICP) (Lindsay and Norvell 1978).

For macro and micromineral element determinations in the plant, P concentration was analyzed with a spectrophotometer (Murphy and Riley 1962) and K (Potassium), Zn, Fe, Mn, and Cu were determined by ICP. The N and C contents in the plant tissue were determined according to the Dumas dry burning method (Grant et al. 2001).

## Agronomic efficiency

Nutrient use efficiencies were determined according to Fageria, Baligar, and Clark (2006).  $\text{AE} (\text{kg grain yield kg}^{-1} \text{P}_2\text{O}_5) = (\text{Gf} - \text{Gu}/\text{Na})$ , AE is agronomic efficiency, Gf is the grain yield of the fertilized plot (kg), Gu is the grain yield of the unfertilized plot (kg), and Na is the quantity of nutrient applied (kg).

## Statistical analysis

The SPSS 22.0 for Windows statistical package program was used to analyze the obtained data for Anova.

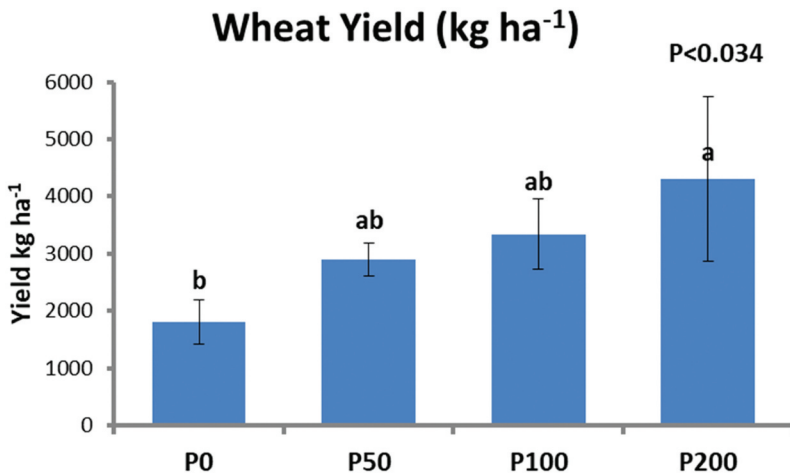
## Results and discussion

### *Wheat yield*

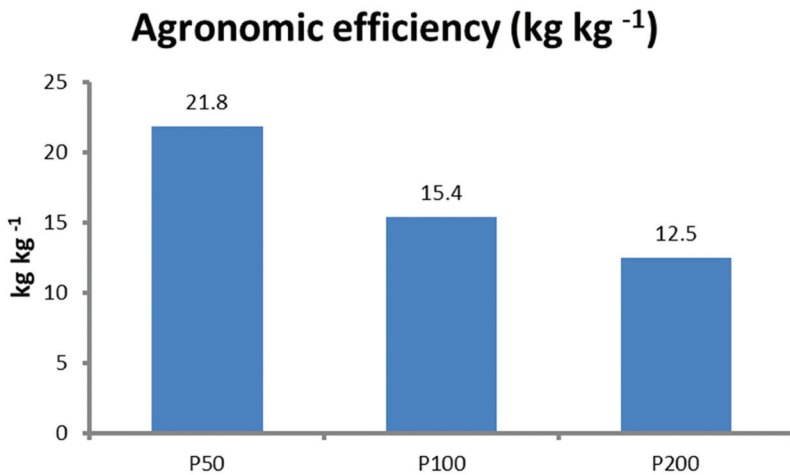
With increasing P doses application, wheat yield increased significantly ( $P < .034$ ). The yield values of the wheat plant were determined, and in the control plots 1807  $\text{kg ha}^{-1}$  yield was obtained, while 2899, 3343 and 4306  $\text{kg ha}^{-1}$  yield were obtained under 50, 100 and 200  $\text{kg P}_2\text{O}_5 \text{ ha}^{-1}$  application, respectively (Figure 1). Since the experiment was set up in 1998, the impact of P fertilizer on yield is different.

### Nutrient use efficiency

The agronomic efficiency (AE) was defined as the economic production obtained per unit of nutrient applied by Fageria, Baligar, and Li (2008). The highest agronomic efficiency was determined in the P50 application made plots with 21.8  $\text{kg grain yield per kg}^{-1} \text{P}_2\text{O}_5$  and the lowest efficiency, 12.5  $\text{kg grain yield per kg}^{-1} \text{P}_2\text{O}_5$ , was obtained with P200 application (Figure 2). Increasing the P doses fertilizer application significantly reduced the agronomic efficiency. Similarly, under the same field conditions (Ortaş and Islam 2018) it was shown that with increasing P fertilizer, P use efficiency decreased significantly. This situation shows that the soils buffer the P applied after a certain amount (Rowell 1994) and in this case it does not have a positive reflection on the yield. The ability of plants to dissolve



**Figure 1.** The effect of phosphorus fertilizer application over the years on the yield of wheat plant.



**Figure 2.** Agronomic nutrient use efficiency of wheat plant (AE (kg grain yield kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>)).

the nutrients in the rhizosphere, better transport, distribution, utilization within plants and balanced resources depends on rhizosphere dynamics (Kuzyakov and Razavi 2019).

This situation asks for a suitable P management. Results of Chu et al. (2020) indicate that under intensive farming systems, the inherent potential of the mycorrhiza pathway can be maximized by managing soil plant P availability to achieve optimal P fertilization.

### Mycorrhizal infection

The mycorrhizal root infection ration in root samples was determined, and it was found that due to increasing P applications mycorrhizal root colonization was significantly decreased ( $P < .089$ ) (Figure 3). In general, under low P input production systems indigenous mycorrhizal colonization increases (Lang et al. 2022) and increasing P application reduces the root infection of many plant species (Smith and Read 2008), including wheat plant.

There is a clear difference between the treatments due to the fact that naturally existing mycorrhizal fungi in the soil, which are affected by the application of P fertilizer. In particular, under field

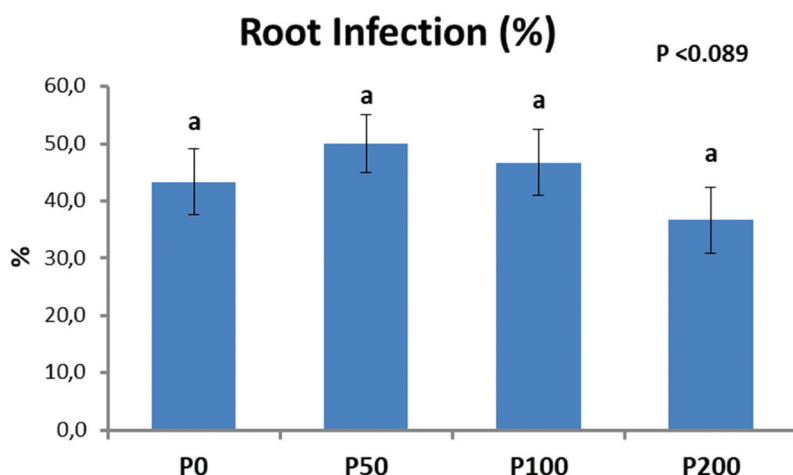


Figure 3. Effects of different doses of P application on % mycorrhizal root infection of plants.

conditions indigenous mycorrhiza formations are active at low P doses due to their contribution to plant nutrient intake and plant growth.

### Soil chemical characteristics

After harvest soil C, N, P and K concentrations were determined. Soil organic C concentration increased with increasing P application rates. At 0–20 cm soil depth, 0.80% C, 1.29% C, 1.18% C and 1.04% C were measured in P0, P50, P100 and P200 applied plots, respectively. In 20–40 cm soil depth, it was determined as 0.54% C, 0.93% C, 0.87% C, and 0.90% C, respectively, as well. In long-term experiments, it has been determined that organic and inorganic fertilizer applications applied to the soil significantly increase the organic C concentration of soils (Ding et al. 2007; Ortas and Lal 2012). Due to plant root development and degradation in the soil, organic C and therefore OM content increased with P doses increases. Similarly, in the present experiment increasing P-level application increases soil organic C concentration (Ortas and Lal 2012). Increasing P application effects on soil OM sequestration is very important, and for future C pool management P fertilization is becoming important.

With the increasing P dose applications, the soil N concentration did not increase. For both soil depths, N concentrations statistically were not significant (Table 2). Fertilizer application to soils

Table 2. The effect of P applications in different doses on  $P_2O_5$ ,  $K_2O$ , N%, C %, C/N ratio and organic matter content in soils.

Soil Deep (cm)	P Doses	$P_2O_5$	$K_2O$	C	N	C/N	OM
		$ha^{-1}$	$ha^{-1}$	%	%		%
0-20	P0	35.2±3.2 <sup>a</sup>	990.7±138.2 <sup>a</sup>	0.80±0.28 <sup>a</sup>	0.18±0.01 <sup>a</sup>	4.34±1.5 <sup>a</sup>	1.38±0.8 <sup>a</sup>
	P50	44.3±21.7 <sup>a</sup>	995.0±68.7 <sup>a</sup>	1.29±0.56 <sup>a</sup>	0.17±0.00 <sup>a</sup>	7.57±3.3 <sup>a</sup>	2.25±1.0 <sup>a</sup>
	P100	56.4±19.4 <sup>a</sup>	844.3±137.9 <sup>a</sup>	1.18±0.32 <sup>a</sup>	0.18±0.02 <sup>a</sup>	6.53±1.2 <sup>a</sup>	2.05±0.5 <sup>a</sup>
	P200	53.9±13.9 <sup>a</sup>	922.3±217.2 <sup>a</sup>	1.04±0.18 <sup>a</sup>	0.16±0.04 <sup>a</sup>	6.88±1.8 <sup>a</sup>	1.82±0.3 <sup>a</sup>
20-40	P0	32.9±7.7 <sup>b</sup>	805.7±158.0 <sup>a</sup>	0.54±0.05 <sup>b</sup>	0.15±0.01 <sup>a</sup>	3.58±0.3 <sup>b</sup>	0.95±0.1 <sup>b</sup>
	P50	29.3±2.3 <sup>b</sup>	762.0±84.9 <sup>a</sup>	0.93±0.04 <sup>a</sup>	0.16±0.01 <sup>b</sup>	5.85±0.1 <sup>a</sup>	1.62±0.1 <sup>a</sup>
	P100	65.9±12.9 <sup>a</sup>	698.3±88.9 <sup>a</sup>	0.87±0.06 <sup>a</sup>	0.15±0.01 <sup>a</sup>	5.81±0.8 <sup>a</sup>	1.52±0.1 <sup>a</sup>
	P200	41.8±6.1 <sup>b</sup>	573.7±119.1 <sup>a</sup>	0.90±0.01 <sup>a</sup>	0.16±0.00 <sup>a</sup>	5.61±0.1 <sup>a</sup>	1.57±0.0 <sup>a</sup>
0-20	3	P<0.697	P<0.681	P<0.428	P<0.649	P<0.341	P<0.429
20-40	3	P<0.002	P<0.159	P<0.366	P<0.001	P<0.001	P<0.001

Mean of three replicates and ± is a standard error.

**Table 3.** Effects of different doses of P applications on Fe, Mn, Cu and Zn contents in soils.

Soil Deep (cm)	P Doses	Fe	Mn	Cu	Zn
		mg kg <sup>-1</sup>			
0-20	P0	5.37±0.13 <sup>a</sup>	7.96±1.55 <sup>a</sup>	2.42±0.02 <sup>a</sup>	0.34±0.05 <sup>a</sup>
	P50	4.46±0.28 <sup>ab</sup>	6.40±0.21 <sup>ab</sup>	2.17±0.08 <sup>a</sup>	0.28±0.03 <sup>a</sup>
	P100	2.25±1.75 <sup>b</sup>	2.60±2.90 <sup>b</sup>	0.86±0.93 <sup>b</sup>	
20-40	P200	4.56±0.26 <sup>ab</sup>	6.67±0.74 <sup>ab</sup>	1.71±0.01 <sup>ab</sup>	1.32±0.99 <sup>a</sup>
	P0	5.33±0.80 <sup>a</sup>	6.32±0.36 <sup>a</sup>	2.18±0.18 <sup>a</sup>	0.66±0.53 <sup>a</sup>
	P50	4.20±0.50 <sup>a</sup>	6.80±1.37 <sup>a</sup>	2.14±0.27 <sup>a</sup>	0.21±0.07 <sup>ab</sup>
	P100	3.49±1.15 <sup>a</sup>	3.91±2.09 <sup>a</sup>	0.91±0.71 <sup>b</sup>	0.17±0.01 <sup>b</sup>
	P200	4.98±1.43 <sup>a</sup>	7.09±0.81 <sup>a</sup>	1.55±0.14 <sup>ab</sup>	0.41±0.15 <sup>a</sup>
0-20	fd				
0-20	3	P<0.015	P<0.021	P<0.016	P<0.177
20-40	3	P<0.207	P<0.067	P<0.014	P<0.048

increases the N concentration of the soils as well as the organic C content of the soil (Coonan et al. 2019). Similarly, Ma et al. (2014) stated that there is a direct relationship between the P content in the soil and the increase in total organic C and total N concentration in the soil.

The C/N ratio was within the expected limits, but in 0–20 cm depth in the control plot soils, the C/N ratio demonstrated to be as low as 4.34, in 20–40 cm soil depth 3.58 and with P-level addition the ratio increased by 50%.

Soil organic C value increased with increasing P dose, probably due to the root and rhizosphere effects produced by the plant. Similarly, soil OM content increased with increasing P dose application. Similarly, Masto et al. (2007) reported that P fertilization may increase soil organic C. Pulleman et al. (2000) reported that plant variety and soil management increased organic C in long-term experiments. Ortas and Lal (2012) in the same experimental area determined that rhizosphere dynamics have an effect on soil C content. Possibly remaining or residue root material increased soil nutrition concentration.

Research findings determined that the extractable soil P content generally increased depending on the application P dose. At 0–20 cm soil depth with P0 application 35.2 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> was measured, with P200 application 53.9 kg ha<sup>-1</sup> was measured (Table 2). At the 20–40 cm soil depth, with P0 dose application 32.9 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> and in P200 dose application 841.8 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> were measured.

It is observed that there are no statistically significant differences in between the extractable K contents in the soil due to the increasing P dose applications.

The Fe content in the soil has generally varied between 2.25 and 5.37 mg kg<sup>-1</sup>, and the values are in the critical range (Table 3). Zn values were generally measured below the critical value of 0.5 mg kg<sup>-1</sup>. However, in P100 dosing, a high value such as 1.32 mg kg<sup>-1</sup> was measured at a depth of 0–20 cm. Mn and Cu concentrations in the soil were found to be in the range of the critical values. Increasing P fertilizer applications did not cause a significant change in extractable microelement contents in soils. Statistically, increasing P application has been found to increase the Fe, Mn and Cu content of the soils (Table 3).

### Mycorrhizal spore numbers

In general, with increasing P application, the total number of spores decreased (Table 4). Generally, with increasing P-level mycorrhizae spores' diversity and abundance were decreased (Liu et al. 2020; Ortas 2003). At 0–20 cm soil depth, increasing P doses application significantly affects the indigenous mycorrhiza spore numbers. In control plants 37.3 spores 10 g soil<sup>-1</sup> were determined, while 18 spores 10 g soil<sup>-1</sup> was determined in the P50 application and 17 spores 10 g soil<sup>-1</sup> in the P200 application

**Table 4.** Effect of different doses of P applications on the number of spores in soils.

Soil Deep (cm)	P Doses	Mycorrhizal Spore
		10g soil <sup>-1</sup>
0-20 cm	P0	37.3±26.8 <sup>a</sup>
	P50	18.0±5.6 <sup>a</sup>
	P100	15.0±7.0 <sup>a</sup>
	P200	17.0±15.7 <sup>a</sup>
20-40 cm	P0	24.0±3.0 <sup>ab</sup>
	P50	14.0±2.0 <sup>b</sup>
	P100	26.0±7.6 <sup>ab</sup>
	P200	40.1±11.2 <sup>a</sup>
0-20	fd	
20-40	3	P<0.356
	3	P<0.013

(Table 4). Similarly, in the control plots, 20–40 cm depth 24 spores and in P200 dose application 40.1 spores 10 g<sup>-1</sup> soil were determined.

### Plant macro and micronutrients concentrations

Plant samples were analyzed for macro and micronutrients. In the control (P0 application), the C (% C) concentration was 37.5% C, and in the P200 doses applied plots grown plant was 39% C (Table 5). With increasing P dose application plant tissues N % concentration increased. In control plot grown plant N concentration was 0.99% N, in P50 applied plots was 1.03% N, in P100 plots was 1.06% N and in P200 applied plots 1.10% N. Also the C/N ratio was calculated and it was found that the measured C/N ratio is ranged in between 34.9 and 38.0. The C/N ratio was measured in the range of 34.9–38.0. As can be seen in Table 2, increasing P fertilizer application also increased soil C and N concentration as well.

P concentration in plant tissue increased with increasing P doses application. In the control plant tissue, %P concentration was below the critical level (Jones 1998) such as 0.10% P. The highest P concentration was determined as 0.17% P in P200 application. The K concentration of plant tissues increased with increasing P dose, however, the K concentration was above the optimum critical limit value for K (1.2%K).

**Table 5.** Effects of different P dose applications on % C, N, P, K, Cu, Fe, Mn and Zn concentrations of plants.

P doses	C	N	P	K	C/N
	%				
P0	37.5±0.8 <sup>a</sup>	0.99±0.03 <sup>a</sup>	0.10±0.02 <sup>b</sup>	1.22±0.09 <sup>a</sup>	38.0±0.5 <sup>a</sup>
P50	37.7±1.2 <sup>a</sup>	1.03±0.06 <sup>a</sup>	0.10±0.01 <sup>b</sup>	1.31±0.03 <sup>a</sup>	36.8±3.1 <sup>a</sup>
P100	37.0±1.8 <sup>a</sup>	1.06±0.05 <sup>a</sup>	0.13±0.04 <sup>ab</sup>	1.31±0.09 <sup>a</sup>	34.9±2.1 <sup>a</sup>
P200	39.0±2.4 <sup>a</sup>	1.10±0.05 <sup>a</sup>	0.17±0.02 <sup>a</sup>	1.38±0.02 <sup>a</sup>	35.4±2.8 <sup>a</sup>
fd					
P doses	P<0.531	P<0.084	P<0.023	P<0.117	P<0.400
P doses	Cu	Fe	Mn	Zn	
	mg kg <sup>-1</sup>				
P0	4.85±0.16 <sup>a</sup>	75.54±1.40 <sup>a</sup>	49.54±4.40 <sup>a</sup>	18.30±2.75 <sup>c</sup>	
P50	4.51±0.16 <sup>a</sup>	78.17±5.56 <sup>a</sup>	49.28±3.63 <sup>a</sup>	24.81±2.41 <sup>bc</sup>	
P100	4.26±0.55 <sup>a</sup>	80.43±3.34 <sup>a</sup>	45.50±6.06 <sup>a</sup>	29.37±1.28 <sup>ab</sup>	
P200	4.23±0.26 <sup>a</sup>	85.97±8.08 <sup>a</sup>	49.28±5.94 <sup>a</sup>	34.46±5.78 <sup>a</sup>	
fd					
P doses	P<0.148	P<0.170	P<0.779	P<0.003	

There was no statistical difference in Cu, Fe and Mn concentrations of the plant with increasing P dose application. However, with increasing P doses application Zn concentration was significantly increased (Table 5). In P0 treatments Zn concentration was 18.30 mg Zn kg<sup>-1</sup> with increasing P50, P100 and P200 doses the concentration was measured 24.81, 29.37 and 34.46 mg Zn kg<sup>-1</sup>, respectively. Previously Ortas and Akpinar (2006) stated that the Zn uptake of the plant decreased with increasing P fertilizer application. At the same time, the effectiveness of mycorrhizal colonization decreases due to the increasing P concentration (Ryan et al. 2008) and the nutrient intake level of the plant decreases.

## Conclusion and recommendations

Wheat yield significantly increased with increased P application rate. At 50 kg ha<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> maximum agronomic efficacy was obtained, and a further P rate increase decreased agronomic efficacy.

High P fertilizer application was negatively correlated with soil mycorrhiza spore number and mycorrhizal root colonization. Plant tissue P, Fe and Zn concentrations were all increased with P fertilizer dose application. Also, with increasing P fertilizer application, plant tissue C and N concentrations increased as well. Long-term P fertilizer application-induced soil P accumulation and increased soil organic C concentration. The obtained results suggest that long-term application of P fertilizers increased plant yield and increased soil and plant C and N concentration, which supports our initial hypothesis.

The long-term experiment should be continued to understand the C accumulation under the P doses application.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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## References

- Carvalho, L. C., P. G. Dennis, D. Fedoseyenko, M. R. Hajirezaei, R. Borriss, and N. von Wirén. 2011. Root exudation of sugars, amino acids, and organic acids by maize as affected by nitrogen, phosphorus, potassium, iron deficiency. *Journal of Plant Nutrition and Soil Science* 174 (1):3–11. doi:10.1002/jpln.201000085.
- Chen, X., N. Jiang, L. M. Condrón, K. E. Dunfield, Z. Chen, J. Wang, and L. Chen. 2019. Impact of long-term phosphorus fertilizer inputs on bacterial phoD gene community in a maize field, Northeast China. *The Science of the Total Environment* 669:1011–18. doi:10.1016/j.scitotenv.2019.03.172.
- Chu, Q., L. Zhang, J. Zhou, L. Yuan, F. Chen, F. Zhang, G. Feng, and Z. Rengel. 2020. Soil plant-available phosphorus levels and maize genotypes determine the phosphorus acquisition efficiency and contribution of mycorrhizal pathway. *Plant and Soil* 449 (1–2):357–71. doi:10.1007/s11104-020-04494-4.
- Coonan, E. C., A. E. Richardson, C. A. Kirkby, J. A. Kirkegaard, M. R. Amidy, R. J. Simpson, and C. L. Strong. 2019. Soil carbon sequestration to depth in response to long-term phosphorus fertilization of grazed pasture. *Geoderma* 338:226–35. doi:10.1016/j.geoderma.2018.11.052.
- Ding, W., L. Meng, Y. Yin, Z. Cai, and X. Zheng. 2007. CO<sub>2</sub> emission in an intensively cultivated loam as affected by long-term application of organic manure and nitrogen fertilizer. *Soil Biology & Biochemistry* 39 (2):669–79. doi:10.1016/j.soilbio.2006.09.024.
- Eichler-Lobermann, B., S. Köhne, and D. Köppen. 2007. Effect of organic, inorganic, and combined organic and inorganic P fertilization on plant P uptake and soil P pools. *Journal of Plant Nutrition and Soil Science* 170 (5):623–28. doi:10.1002/jpln.200620645.
- Fageria, N. 2012. The role of soil organic matter in maintaining sustainability of cropping systems. *Communications in Soil Science and Plant Analysis* 43 (16):2063–113. doi:10.1080/00103624.2012.697234.
- Fageria, N. K., V. C. Baligar, and R. B. Clark. 2006. *Physiology of crop production*. (1st ed.), 356. Boca Raton: CRC Press.

- Fageria, N. K., V. C. Baligar, and Y. C. Li. 2008. The role of nutrient efficient plants in improving crop yields in the twenty first century. *Journal of Plant Nutrition* 31 (6):1121–57. doi:10.1080/01904160802116068.
- Gerdermann, J. W., and T. H. Nicolson. 1963. Spores of mycorrhizal Endogone species extracted from soil by wet sieving and decanting. *Transactions of the British Mycological Society* 46 (2):235–44. doi:10.1016/S0007-1536(63)80079-0.
- Giovannetti, M., and B. Mosse. 1980. An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. *The New Phytologist* 84 (3):489–500. doi:10.1111/j.1469-8137.1980.tb04556.x.
- Gollner, M. J., H. Wagentrustl, P. Liebhard, and J. K. Friedel. 2011. Yield and arbuscular mycorrhiza of winter rye in a 40-year fertilisation trial. *Agronomy for Sustainable Development* 31 (2):373–78. doi:10.1051/agro/2010032.
- Grant, R. F., N. G. Juma, J. Robertson, R. C. Izaurralde, and W. B. McGill. 2001. Long-term changes in soil carbon under different fertilizer, manure, and rotation: Testing the mathematical model ecosys with data from the Breton plots. *Soil Science Society of America Journal* 65 (1):205–14. doi:10.2136/sssaj2001.651205x.
- Jones, J. B. 1998. *Plant nutrition manual*. London: Crc Press.
- Koske, R. E., and J. N. Gemma. 1989. A modified procedure for staining roots to detect VA mycorrhizas. *Mycological Research* 92 (4):486–88. doi:10.1016/S0953-7562(89)80195-9.
- Kuzyakov, Y., and B. S. Razavi. 2019. Rhizosphere size and shape: Temporal dynamics and spatial stationarity. *Soil Biology & Biochemistry* 135:343–60. doi:10.1016/j.soilbio.2019.05.011.
- Lang, M., C. Zhang, W. Su, X. Chen, C. Zou, and X. Chen. 2022. Long-term P fertilization significantly altered the diversity, composition and mycorrhizal traits of arbuscular mycorrhizal fungal communities in a wheat-maize rotation. *Applied Soil Ecology* 170. doi:10.1016/j.apsoil.2021.104261.
- Lindsay, W. L., and W. A. Norvell. 1978. Development of a dtpa soil test for zinc, iron, manganese, and copper. *Soil Science Society of America Journal* 42 (3):421–28. doi:10.2136/sssaj1978.03615995004200030009x.
- Liu, S., J. Xu, H. Hong, J. Zhu, J. Tang, and X. Chen. 2020. Changes in the mycorrhizal fungal community in host roots over five host generations under low and high phosphorus conditions. *Plant and Soil* 456:27–41. doi:10.1007/s11104-020-04694-y.
- Masto, R. E., P. K. Chhonkar, D. Singh, and A. K. Patra. 2007. Soil quality response to long-term nutrient and crop management on a semi-arid Inceptisol. *Agriculture, Ecosystems & Environment* 118 (1–4):130–42. doi:10.1016/j.agee.2006.05.008.
- Ma, X., Z. Wu, L. Chen, B. Zhou, Z. Gao, X. Hao, and J. Zhang. 2014. Effect of long-term fertilization on the phosphorus content of black soil in Northeast China. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science* 63:156–61. doi:10.1080/09064710.2014.896934.
- Murphy, J., and J. P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica chimica acta* 27:31–36. doi:10.1016/S0003-2670(00)88444-5.
- Olsen, S. R., C. V. Cole, F. S. Watanabe, and L. A. Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. In *Circular*, Vol. 939, 19. Washington, D.C: U.S. Dept. of Agriculture.
- Ortas, I. 2003. Effect of selected mycorrhizal inoculation on phosphorus sustainability in sterile and non-sterile soils in the Harran Plain in South Anatolia. *Journal of Plant Nutrition* 26 (1):1–17. doi:10.1081/PLN-120016494.
- Ortas, I. 2019. Under field conditions, mycorrhizal inoculum effectiveness depends on plant species and phosphorus nutrition. *Journal of Plant Nutrition* 42 (18):2349–62. doi:10.1080/01904167.2019.1659336.
- Ortas, I., and C. Akpınar. 2006. Response of kidney bean to arbuscular mycorrhizal inoculation and mycorrhizal dependency in P and Zn deficient soils. *Acta Agriculturae Scandinavica, Section B - Soil & Plant Science* 56 (2):101–09. doi:10.1080/09064710510029196.
- Ortas, I., and A. Bykova. 2020. Effects of long-term phosphorus fertilizer applications on soil carbon and CO<sub>2</sub> flux. *Communications in Soil Science and Plant Analysis* 51 (17):2270–79. doi:10.1080/00103624.2020.1822381.
- Ortas, I., and R. Lal. 2012. Long-term phosphorus application impacts on aggregate-associated carbon and nitrogen sequestration in a vertisol in the Mediterranean Turkey. *Soil Science* 177 (4):241–50. doi:10.1097/SS.0b013e318245d11c.
- Ortaş, I., and R. Islam. 2018. Phosphorus fertilization impacts on corn yield and soil fertility. *Communications in Soil Science and Plant Analysis* 49 (14):1684–94. doi:10.1080/00103624.2018.1474906.
- Pulleman, M. M., J. Bouma, E. A. van Essen, and E. W. Meijles. 2000. Soil organic matter content as a function of different land use history. *Soil Science Society of America Journal* 64 (2):689–93. doi:10.2136/sssaj2000.642689x.
- Richardson, A. E., J. P. Lynch, P. R. Ryan, E. Delhaize, F. A. Smith, S. E. Smith, P. R. Harvey, M. H. Ryan, E. J. Veneklaas, H. Lambers, et al. 2011. Plant and microbial strategies to improve the phosphorus efficiency of agriculture. *Plant and Soil* 349 (1):121–56. doi:10.1007/s11104-011-0950-4.
- Rowell, D. L. 1994. *Soil science: Methods and applications/David L. Rowell* 350. Harlow, Essex: New York: Longman Scientific & Technical; Wiley.
- Ryan, M. H., J. K. McInerney, I. R. Record, and J. F. Angus. 2008. Zinc bioavailability in wheat grain in relation to phosphorus fertiliser, crop sequence and mycorrhizal fungi. *Journal of the Science of Food and Agriculture* 88 (7):1208–16. doi:10.1002/jsfa.3200.
- Smith, S. E., and D. Read. 2008. *Mycorrhizal symbiosis*. London: Academic Press.

- Van der Bom, F. J. T., T. I. Mc Laren, A. L. Doolette, J. Magid, E. Frossard, A. Oberson, and L. S. Jensen. 2019. Influence of long-term phosphorus fertilisation history on the availability and chemical nature of soil phosphorus. *Geoderma* 355:1–12. doi:10.1016/j.geoderma.2019.113909.
- Verloop, J., J. Oenema, S. L. G. Burgers, H. F. M. Aarts, and H. van Keulen. 2010. P-equilibrium fertilization in an intensive dairy farming system: Effects on soil-P status, crop yield and P leaching. *Nutrient Cycling in Agroecosystems* 87 (3):369–82. doi:10.1007/s10705-010-9344-x.
- Yucel, D., C. Yucel, and I. Ortas. 2020. Chemical fertilization and organic amendments impact on soil biological, chemical properties and carbon, nitrogen lability. *Fresenius Environmental Bulletin* 29 (9):7488–501.