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Research Paper

Effect of Different Levels of Phosphorus on Availability of Micronutrients in Soils and Their Uptake by Rice Under Submerged and Aerobic Conditions

K.M.S. Kodikara[1*], P.S. Sangwan[2]

[1] *Regional Agriculture Research & Development Center (RARDC), Bandarawela, Sri Lanka*

[2] *Department of Soil Science, Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana, India*

[*]*Corresponding author: manojkodikara@gmail.com*

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Abstract

The effect of added Phosphorus on the availability of micronutrients (Zn, Mn, Cu and Fe) in soils and their uptake by rice were studied under submerged and aerobic water regimes as main factors, and five levels of phosphorus (0, 20, 40, 60 and 80 kg P_2O_5 ha^{-1}) as sub-factors in a factorial RCBD with three replications. Submerged conditions increased soil Fe and Mn availabilities significantly (*P*=0.05) up to a considerable period of plant growth while Cu was only at the early stage. The aerobic conditions reported higher Zn availability at 40 days after Phosphorus application. P application affected only Fe availability at the early stage of the crop. Concentrations of Mn, Fe and Zn in grain and Mn and Fe in straw was increased significantly (*P*<0.05) in submerged conditions. Levels of P application did not significantly (*P*>0.05) influence the micronutrient concentrations in grain or straw except Fe in grain. Submerged condition increased uptake of all micronutrients while the rate of P level over 40 kg P_2O_5 ha^{-1} did not significantly (*P*>0.05) increase the micronutrient uptake by grain and straw. Growing rice under the submerged conditions with 40 kg P_2O_5 ha^{-1} can be recommended to ascertain sufficient levels of availability and optimum uptake of micronutrients by rice plants growing in the studied soil.

Keywords: **Aerobic, Micronutrients, P levels, Rice, Submerge, Uptake**

Introduction

Rice is grown in both, lowland as well as upland ecosystems. Lowland rice, also known as flooded, submerged or irrigated rice is grown on leveled lands with bunds to keep standing water during crop establishment and/or the vegetative and early reproductive growth stages. Upland rice, also known as aerobic rice, is generally grown on undulated and unbounded fields and basically depends on rainfall. Upland rice soils are not intentionally submerged during any part of the crop growth. Yields in lowland rice are much higher than in upland rice due to assured water supply and high inputs (Fageria *et al*., 2011). Water logging and intermittent irrigation of paddy soils affect soil pH, temperature, redox potential (Eh), organic matter, leaching, ion exchange, microbial activity (Zheng and Zhang, 2011) and nutrient availability (Unger *et al*., 2009).

Among plant nutrients, phosphorus (P) is considered as an essential nutrient, and plays a vital role in plant growth. Most soils usually have low levels of native available P emanating from the parent materials and some factors are affecting P solubility. Availability of P depends on the P fractions, which influence on primary productivity of agricultural ecosystems. In long-term fertilization, P is adsorbed and precipitated with different ions in the soil while becoming unavailable for plants because of, rapid formation of non-labile P forms after P incorporation (Ahmed *et al*., 2019). Low P availability leads to its deficiency more commonly in upland conditions compared to submerged conditions due to the formation of poorly soluble complexes in upland, predominantly P reacts with Fe and Al in acid soils and Ca in neutral to alkaline soils. As the redox potential and pH change after flooding, P is released rapidly from some of these compounds. Fayaz *et al*. (2014) opined that appropriate management of phosphatic fertilizers is a major concern for rice soils and the application of various types of chemical phosphatic fertilizers for supplying adequate quantities of P for P-deficient soil is essential to increase crop growth and rice yield. The requirement of P fertilizer depends not only on the crop P demand, but also on the amount of extractable soil P and the soil P fixing capacity.

Fertilization practices may have a significant, although not always positive, effect on soil properties. However, continued long-term P application can lead to its accumulation in surface horizons more than that required for optimum crop growth and may create different antagonism effects on the other nutrients or increasing the potential for P loss to surface water and eutrophication (Sui *et al*., 1999; McDowell *et al*., 2001).

Deficiency or unavailability of micronutrients is the result of various factors, such as calcareous nature and alkaline reactions in soils, the introduction of high yielding varieties, low organic matter, and imbalanced use of nutrients or excess of certain phosphatic fertilizers (Timmer and Teng, 1990). Excess and imbalanced or high rate of P fertilizer application may affect the availability of micronutrients (Zn, B, Cu, Fe, and Mn), leading to reduced crop yields and are designated as P-induced micronutrient disorders. Nevertheless, phosphorus-induced micronutrient deficiency is not common in all soils, crop species, and environmental conditions, but it has been widely reported in various soils and crops (Fayaz *et al*., 2014). The objective of this study was to find out the availability and plant uptake of Zn, Fe, Mn, and Cu under different P levels in submerged and aerobic rice.

Materials and Methods

The field experiment was conducted from June to October (*kharif*) 2018 and 2019 under the wheat-rice cropping system at Rice Research Station, Kaul (Kaithal) of Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), India, situated at a latitude 29° 51' N, longitude 76° 41' E and an altitude of 241 m above mean sea level. Kaul has a sub-tropical and sub-humid climate with average annual rainfall is about 700 mm of which around 80 percent is received during the period from July to September. The temperature may rise to 45 °C and drops down to 5 °C during the summer and winter months, respectively.

The experiment was laid out in a factorial Randomized Complete Block Design (RCBD) with three replications applying two water regimes [(submerged- Transplanted rice (TPR) and Aerobic-Direct seeded rice (DSR)] as main factors and five levels of phosphorus (0, 20, 40, 60 and 80 kg P_2O_5 ha^{-1}) as sub-factors. One meter buffer zone was maintained around every 12 m^2 (4 m x 3 m) plot to control the nutrient contamination. Rice (var. HKR 127) was sown / transplanted in row to row and plant to plant spacing of 20 and 15 cm, respectively.

Direct seeded crop (aerobic) was fertilized with Urea to provide N and the quantity applied was 25% higher (187.5 kg N ha^{-1}) than that of the recommended dose (150 kg N ha^{-1}) applied in three equal splits in 20, 40 and 60 days after seeding (DAS). Transplanted rice (submerged) fertilized with urea as per the recommendation in three equal splits as basal, 21 and 42 days after transplanting. Single super Phosphate was used to provide P and the applied quantities were varying with the treatments. Since the K content in the experimental site was high (320 kg ha^{-1}), no additional amount of K was provided however, 25 kg ha^{-1} of $ZnSO_4$ was applied at the time of seed sowing or transplanting.

Composite surface (0-15 cm) soil samples were collected from each plot separately, using a soil augur, before and 40, 60, 80 and 100 days after phosphorus application (DAPA) and at the time of harvesting. Collected soil samples were prepared following the recommended protocol and stored until chemical analysis. Grain and straw samples were collected randomly at the time of harvesting and oven dried and ground samples were stored separately. Air-dried soil samples were used for all analysis. Soil available micronutrients (Zn, Fe, Mn and Cu) were extracted using DTPA extractant and quantified using Atomic Absorption Spectrophotometer

(AAS) model Varian-Spectra AA-240 FS as described by Lindsay and Norvell (1978). Grain and straw samples were digested in a mixture of nitric acid and perchloric acid (9:1) in a digestion chamber and Zn, Fe, Mn and Cu contents were measured with the same ASS. The uptake of Zn, Fe, Mn and Cu were calculated using the following formula:

Nutrient uptake = Nutrient conc. in grain or straw × grain or straw oven dry yield

Analysis of variance (ANOVA) was carried out and the least significant differences were calculated for statistical comparison of treatment means at 5% level of significance using OPSTAT (Sheoron *et al*., 1998).

Results and Discussion

Physico-chemical properties of the experimental site

The initial physico-chemical properties of the soil in the experimental site are presented in Table 1. The soil can be described as slightly alkaline with non-saline nature while containing low organic carbon. Available N, P and K were categorized as low, medium and high respectively. Zn, Fe, Mn and Cu can be classified as medium, high, medium and too high, respectively based on Alloway (1995).

Table 1. Physico-chemical properties of soil of the experimental site

Soil property	Value	Soil property	Value
pH(1:2)	7.65	Available K	320.0 kg ha^{-1}
EC(1:2)	0.30 dS m^{-1}	Available Zn	1.23 mg kg^{-1}
Organic carbon	0.73 %	Available Fe	16.32 mg kg^{-1}
Available N	142.0 kg ha^{-1}	Available Mn	4.75 mg kg^{-1}
Available P	11.0 kg ha^{-1}	Available Cu	2.18 mg kg^{-1}

Table 2. Effect of P on DTPA extractable Zn (mg kg^{-1}) under submerge (Sub.) and aerobic (Aero.) conditions

P_2O_5 levels (kg ha^{-1}) (P)		Days After Phosphorus Application (DAPA)									
		40		60		80		100		140	
		Water regimes (W)									
		Aero.	Sub.	Aero.	Sub.	Aero.	Sub.	Aero.	Sub.	Aero.	Sub.
0		1.58	1.54	1.54	1.54	1.54	1.54	1.55	1.54	1.58	1.58
20		1.57	1.55	1.55	1.55	1.55	1.55	1.56	1.55	1.57	1.56
40		1.57	1.55	1.55	1.55	1.55	1.55	1.57	1.55	1.57	1.54
60		1.54	1.52	1.57	1.52	1.57	1.52	1.57	1.57	1.54	1.56
80		1.55	1.51	1.57	1.51	1.57	1.51	1.55	1.57	1.55	1.55
LSD (*P*=0.05)	W	0.02		NS		NS		NS		NS	
	P	NS		NS		NS		NS		NS	
	W x P	NS		NS		NS		NS		NS	

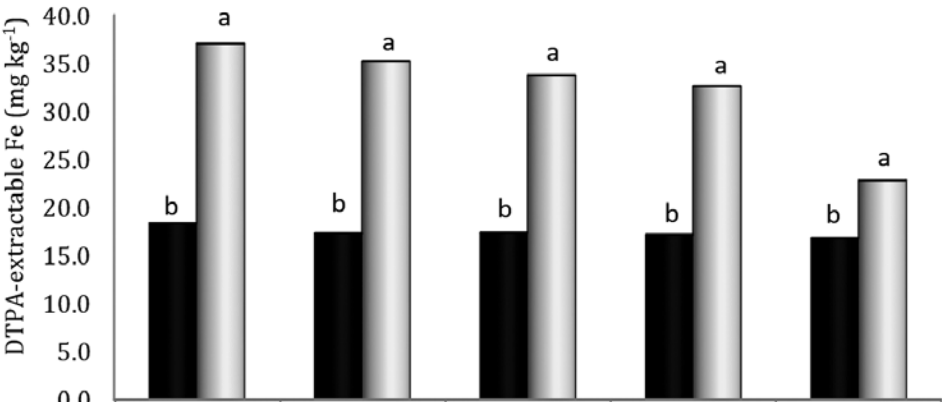
Available Zinc (Zn)

A significantly lower level of available Zn was observed in submerged condition compared to the aerobic condition at 40 DAPA. However, P application or the quantity applied did not affect the Zn availability in both water regimes. There was no significant interaction between water regimes and P applications on Zn availability (Table 2).

Zinc availability generally decreased after the flooding of rice soils (Fageria *et al*., 2011) as observed in the present experiment because submergence of soil depressed the availability of Zn in rice-growing soils (Ponnamperuma. 1972; Sahrawat. 2005). No definite pattern or relationship was observed in Zn availability and time elapsed after P application. The reduction of available Zn was not observed with graded P levels (Table 02) in both water regimes. The availability of cationic micronutrients like Zn decreased with the application of graded P to soil due to the formation of insoluble forms of Zn such as Zn-phosphate (Ali *et al*., 2014). Similar negative interactions between phosphorus and Zn were earlier reported by Mandal and Haldar (1990) because they observed that applied phosphorus reduced the available Zn content in soils. Available Zn in samples collected at different DAPA was higher than that of initial soil (1.23 mg kg^{-1}) may be due to $ZnSO_4$ application at the rate 25 kg ha^{-1} at the time of seed sowing or transplanting.

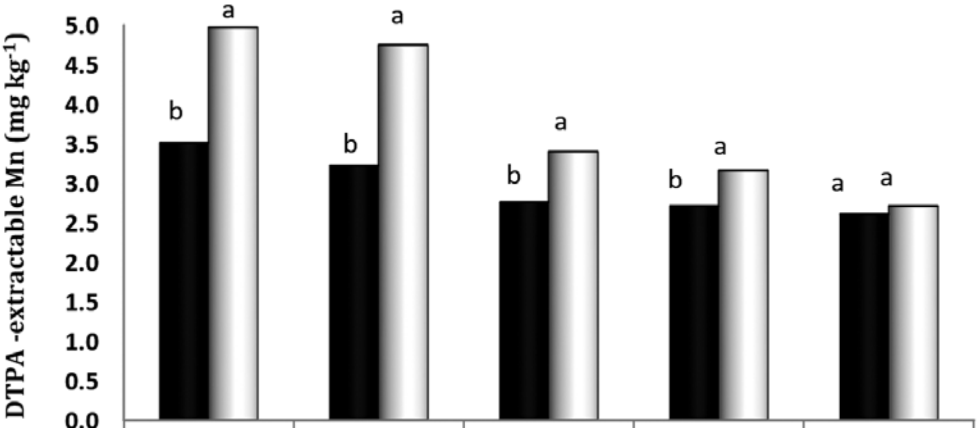
Available Iron (Fe)

Significantly higher Fe was available in submerged soil than in aerobic soil (Figure 01) and the difference was higher in the early period of the experiment while it decreased with time. The main reason for the increased availability of Fe in submerged soil is the reduction of low soluble Fe^{+3} compounds into highly soluble Fe^{+2} compounds (Fageria *et al*., 2008).



	40 DAPA	60 DAPA	80 DAPA	100 DAPA	140 DAPA
Aero.	18.34	17.3	17.36	17.16	16.8
Sub	37.02	35.2	33.74	32.59	22.79

Figure 1. Effect of P levels on DTPA extractable Fe (mg kg^{-1}) under submerge (Sub.) and aerobic (Aero.) conditions



	40 DAPA	60 DAPA	80 DAPA	100 DAPA	140 DAPA
■ Aero.	3.51	3.22	2.76	2.71	2.61
□ Sub	4.97	4.75	3.40	3.16	2.71

Figure 2. Effect of P levels on DTPA extractable Mn (mg kg^{-1}) under submerge (Sub.) and aerobic (Aero.) conditions

Available Manganese (Mn)

The most important chemical change that takes place in submerged soil is the reduction of iron and the accompanying increase in its solubility (Ponnamperuma. 1972). Available Fe gradually decreased in all treatments with respect to DAPA. Similarly, Sahai *et al*. (2016) reported that the DTPA extractable micronutrient content increased at the early stage and reduced in later stages of incubation. The effect of different levels of P on Fe availability was significant only at 40 DAPA and insignificant thereafter. No significant interaction between water regimes and P levels was found throughout the experimental period perhaps due to the positive interactions between applied phosphorus and Fe and this is in line with our observations.

Available Mn was significantly influenced by water regimes up to 100 DAPA (Figure 1). Relatively high values of available Mn were recorded in submerged conditions over the aerobic condition. Fageria *et al*. (2008) and Bhaduri *et al*. (2017) reported that Mn^{4+} reduces into Mn^{2+} in flooded soils consequently increasing its availability. Ponnamperuma (1972) reported that an increase in the concentration of water-soluble Mn^{2+}, precipitation of manganous carbonate and re-oxidation of Mn diffusing or moving by mass flow to oxygenated interfaces in the submerged soil by increasing the availability of Mn.

Ali *et al*. (2014) reported that phosphorus application on the availability of micronutrients was insignificant but the application of P increased the concentrations of Mn, perhaps due to the positive interactions between applied phosphorus and Mn.

However, results of the present experiment did not support the observations of Ali *et al*. (2014) and this may be due to the alkaline nature of the experimental soil. Available Mn content showed decreasing trend with respect to DAPA in both water regimes.

Sahai *et al*. (2016) also reported that contents of DTPA extractable cationic micronutrients are increased in early periods while declining at later stages of incubation and the reasons for that the uptake of Mn by crop plants and slowing down of Mn flux to the soil solution at the later stages of the incubation. A similar scenario may have affected the changes of Mn in the study.

Available Copper (Cu)

Available Cu was significantly changed in different water regimes only at 40 DAPA. Available Cu in all samples was insignificant including P levels and interactions (Table 5).

Fageria *et al*. (2011) mentioned that Cu concentrations generally decreased after flooding due to an increase in the pH of acid soils. Nevertheless, in the current study, it was found that soil pH decreased after flooding due to its alkaline nature, which may be the reason to increase in available Cu at an early stage (40 DAPA) of the study.

Application of P fertilizer reported no significant effect on available Cu in study soils. Ali *et al*. (2014) observed that applied P insignificantly affected available Cu but reported a decreasing trend in available Cu with increasing P levels. That may be due to the formation of insoluble forms of Cu, such as Cu-phosphate.

Table 5. Effect of P levels on DTPA extractable Cu (mg kg^{-1}) under submerge (Sub.) and aerobic (Aero.) conditions

P_2O_5 levels (kg ha^{-1}) (P)		Days After Phosphorus Application (DAPA)									
		40		60		80		100		140	
		Water regimes (W)									
		Aero.	Sub.	Aero.	Sub.	Aero.	Sub.	Aero.	Sub.	Aero.	Sub.
0		2.19	2.21	2.17	2.20	2.19	2.21	2.19	2.20	2.17	2.21
20		2.16	2.23	2.16	2.19	2.19	2.23	2.16	2.19	2.16	2.23
40		2.19	2.23	2.19	2.19	2.15	2.23	2.19	2.19	2.19	2.23
60		2.18	2.21	2.19	2.19	2.17	2.21	2.18	2.19	2.19	2.21
80		2.19	2.20	2.16	2.18	2.17	2.20	2.19	2.18	2.16	2.20
LSD	W	0.03		NS		NS		NS		NS	
(*P*=0.05)	P	NS		NS		NS		NS		NS	
	PxW	NS		NS		NS		NS		NS	

Micronutrient concentrations and uptake in rice grain and straw

A perusal of data (Tables 06 and 07) revealed that the content of Mn and Fe in both grain and straw was influenced significantly by submerged and aerobic conditions. In general micronutrient contents in grain and straw were significantly superior in submerged conditions over aerobic conditions. Straw recorded a higher concentration of micronutrients except for Cu in aerobic conditions. Dass *et al*. (2017) observed different behaviors in grain and straw micronutrient contents in different moisture regimes. Further noticed that Fe and Mn concentrations of grain and straw significant increase with increasing the soil moisture by flooding more days but Zn and Cu displayed different changes of concentrations in grains and straw against the moisture regimes. Levels of P application did not influence the micronutrient concentrations in grain or straw significantly except Fe in grain. Our results showed the sequence of micronutrient concentrations in grain and straw was in the order of Fe>Zn>Mn>Cu and Fe>Mn>Zn>Cu, respectively in both water regimes while showing similar changes of micronutrient concentration in 2018 and 2019 *kharif*.

Table 6. Zn, Mn, Cu and Fe concentration in grain and straw and their uptake during 2018 *kharif*

Treatment		Concentration (mg kg^{-1})				Uptake (g ha^{-1})			
		Zn	Mn	Cu	Fe	Zn	Mn	Cu	Fe
Water regWater regime									
Aero.	G	12.33	9.85	2.73	29.32	61.22	48.91	13.52	146.16
	S	27.23	29.28	2.36	112.12	151.51	163.39	13.15	622.24
Sub.	G	12.53	11.07	2.32	37.61	79.89	70.24	14.73	238.92
	S	27.76	48.00	2.47	147.66	207.76	360.44	18.44	1105.15
LSD	G	NS	0.43	NS	1.88	4.33	3.82	0.66	14.64
(*P*=0.05)	S	0.29	4.48	NS	1.4	10.06	42.83	1.00	49.15
P level									
0	G	12.43	10.09	2.54	30.43	60.95	50.02	12.08	152.53
	S	27.40	36.64	2.37	130.79	154.02	217.72	13.34	731.89
20	G	12.37	10.41	2.53	32.30	68.32	57.62	13.78	181.70
	S	27.40	37.65	2.36	129.44	174.42	247.63	15.04	820.84
40	G	12.25	10.52	2.51	35.33	72.98	63.05	14.88	211.98
	S	27.23	38.13	2.43	126.98	187.30	268.93	16.72	873.25
60	G	12.53	10.59	2.53	34.36	74.55	63.28	14.90	206.07
	S	27.58	37.82	2.43	129.72	189.71	266.74	16.73	892.64
80	G	12.58	10.66	2.52	34.89	75.98	63.92	14.98	210.43
	S	27.88	42.95	2.48	132.54	192.72	308.55	17.15	915.47
LSD	G	NS	NS	NS	2.97	6.86	6.04	1.05	23.14
(*P*=0.05)	S	NS	NS	NS	NS	15.90	26.79	1.59	77.71

Aero. – Aerobic, Sub. – Submerge, G – Grain, S – Straw

Both water regimes reported the same sequence of magnitude of grain nutrient uptake as Fe>Zn>Mn>Cu while reported Fe>Mn>Zn>Cu in straw in both water regimes and years. Dass *et al*. (2017) reported that micronutrient uptake was significantly influenced by moisture regime and observed higher moisture regimes increased Fe and Mn uptake remarkably while Zn and Cu performed differently. They noted that the sequence of uptake by grain and straw of rice followed the orders of Fe>Mn>Zn>Cu and Mn>Zn>Fe>Cu, respectively under differing crop management and soil moisture regimes. Phosphorus application exhibited a significant increase in micronutrient uptake by grain and straw up to 40 kg P_2O_5 ha^{-1} while submerged condition also exerted a significant influence on the uptake of Zn, Mn, Cu and Fe during the period of experimentation.

Experimental results revealed that the submerged water regime increased significantly grain and straw yield by 27.9% and 34.5%, respectively over aerobic conditions. P application rate up to 40 kg ha^{-1} under aerobic conditions increased grain yield significantly and further increases did not affect significantly (Data not shown), similar to the results of Kodikara *et al*., (2019).

Table 7. Zn, Mn, Cu and Fe concentration in grain and straw and their uptake during 2019 *kharif*

		Concentration (mg kg^{-1})				Uptake (g ha^{-1})			
		Zn	**Mn**	**Cu**	**Fe**	**Zn**	**Mn**	**Cu**	**Fe**
Water regime									
Aero.	G	11.82	9.58	2.79	30.12	58.63	47.32	13.92	177.93
	S	26.87	29.57	2.28	113.39	175.90	193.78	14.93	741.45
Sub.	G	12.09	10.50	2.27	38.47	76.74	66.64	14.40	292.33
	S	27.30	48.42	2.34	149.53	237.59	420.62	20.40	1302.13
LSD	G	NS	0.71	NS	1.47	5.15	4.98	0.42	23.20
(*P*=0.05)	S	0.32	4.45	NS	12.58	18.73	40.89	1.30	76.05
P level									
0	G	12.03	10.10	2.48	30.42	59.02	49.65	13.98	171.21
	S	27.01	37.04	2.24	131.62	177.57	250.00	14.72	876.50
20	G	11.87	9.92	2.51	32.30	65.58	54.58	16.55	212.73
	S	27.03	38.15	2.28	130.60	200.93	293.81	16.93	990.07
40	G	11.80	10.01	2.53	32.99	70.35	60.08	18.20	236.87
	S	26.73	38.48	2.35	128.15	213.92	317.85	18.81	1045.27
60	G	12.20	10.12	2.51	33.02	72.63	72.76	14.75	237.28
	S	27.12	38.11	2.31	132.05	221.24	320.66	18.97	1100.70
80	G	11.88	10.24	2.50	33.73	70.87	61.35	14.84	243.43
	S	27.53	39.76	2.37	134.87	220.07	353.68	18.87	1096.41
LSD	G	NS	NS	NS	2.03	8.14	7.61	1.69	20.87
(*P*=0.05)	S	NS	NS	NS	NS	13.82	48.71	2.06	72.81

Aero. – Aerobic, Sub. – Submerge, G – Grain, S – Straw

Conclusions

Submerged conditions increased micronutrient availabilities in the soil except for Zn, while P application did not significantly affect Mn, Zn and Cu availabilities except Fe. The interaction was insignificant between water regimes and phosphorus application. Submerged conditions increased concentrations of Mn and Fe in grain and straw and Zn in grain while all micronutrient contents were higher in rice plants grown under submerged conditions. P application did not influence on micronutrient concentrations in grain or straw except Fe in grain. Submerged conditions increased the uptake of all micronutrients (Zn, Mn, Cu and Fe) and it was also true with P fertilizer. Increase of grain and straw micronutrient uptake optimized at 40 kg P_2O_5 ha^{-1}. Growing of rice under submerged conditions with the application of 40 kg P_2O_5 ha^{-1} can be recommended to obtain sufficient micronutrient availabilities and crop yield while optimizing micronutrient uptakes in the studied soil.

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