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Root-induced Changes in the Rhizosphere of Extreme High Yield Tropical Rice: 1. Soil Chemical Properties

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ABSTRACT

Root-induced Changes in the Rhizosphere of Extreme High Yield Tropical Rice: 1. Soil Chemical Properties (E Purnomo, M Turjaman, A Hairani, A Mursyid, D Choiron, R Yulia and M Osaki): Padi Panjang cultivar is one of many local rice cultivars found in South Kalimantan that yields 8 Mg ha^{-1} without fertilizer after last transplanting. The mechanisms involved in sustaining nutrient supply to sustain the extreme high yield are of interest. The following work aims to investigate the changes of soil chemical properties in rizhosphere of Padi Panjang cultivar. The Padi Panjang cultivar was grown in a rhizobox filled with soils from 3 different villages in Banjar Regency, South Kalimantan Province, namely, Kuin, Bunipah and Guntung Papuyu. The rice plant was grown for 5 weeks. At the end of the growing period, soil chemical properties such as pH, aluminum (Al), phosphorus (P), potassium (K^+), ammonium (NH_4^+), and nitrate (NO_3^-) were measured. The results showed that Padi Panjang cultivar had the capability to change the soil chemical properties in the rhizophere. The impact was more extent compared with IR64 cultivar. The changes were depended on soil character, especially, soil texture. The soil from Guntung Papuyu was the least affected by root. It was observed that Padi Panjang cultivar acidified more than IR64. A depletion zone of K^+ and NH_4^+ was found in the rhizosphere of both Padi Panjang and IR64 cultivars. The depletion zone of these ions could reach as far as 3 cm from the rhizosphere. For P, the depletion zone only occurred in the rhizosphere soil of IR64 cultivar. However, for Padi Panjang cultivar, the depletion zone of P did not exist. The Padi Panjang cultivar was able to maintain P concentration the same as or higher than control soil without plant. This is the first report showing that Padi Panjang cultivar can be considered as efficient lowland rice cultivar in absorbing not only P but also K in a P- and K-deficient-soil.

Keywords: Local rice, nitrogen, phosphorus, potassium, Padi Panjang, South Kalimantan, tidal swamp

INTRODUCTION

The local farmers in South Kalimantan, Indonesia used to grow local rice in tidal swamp area. They have more hundreds local cultivars grown by the local farmers. Some of them yield more than 3 Mg ha^{-1} without fertilizer (Hasegawa *et al*. 2004). Our previous study (Purnomo *et al*. 2010) found that there was a local rice cultivar, called Padi Panjang, yielded 8 Mg ha^{-1}. This local rice cultivar originated from Kuin village, Banjar Regency, South Kalimantan. We did not find any relationship between soil chemical properties measured with yield of Padi Panjang cultivar. This indicates there may be other mechanisms driven the nutrient supply to sustain such an extreme high yield, such as rhizosphere function.

Rhizosphere is defined as a zone of soil under direct influence of plant root. Some studies had shown rhizosphere soil differs from bulk soil (Eo and Nakamoto 2006). Previous studies had shown the effect of root in influencing the rhizosphere soil. Compared to bulk soil, rhizosphere soil had lower

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pH (Grinsted *et al.* 1982; Begg *et al.* 1994) and nutrient concentrations, such as NH_4, Ca, Mg, and K (Yanai *et al.* 2003), and P (Li *et al.* 1991; Gahoonia *et al.* 1994; Luster *et al.* 2009).

This work focuses on investigating the function of rhizosphere of the Padi Panjang cultivar. According to Hinsinger *et al.* (2005) the rhizosphere differs from the bulk soil in a range of biochemical, chemical and physical processes that occur as a consequence of root growth, water and nutrient uptake, respiration and rhizodeposition. Therefore, this research aims to study the effect of rhizosphere on changes of soil chemical properties.

MATERIALS AND METHODS

Soil

Soils used for the experiment were collected from the three villages, namely, Kuin, Bunipah and

Table 1. Selected soil properties.

No.	Soil Properties*)	Soil origin**) Kuin (3°22'24''S; 114°32'19''E)	Bunipah (3° 27'52''S; 114 °32'54''E)	Guntung Papuyu (3 °27'44''S; 114 °36'50''E)
1.	Particle size analysis (%)[1]			
	Sand	2.08	2.51	0.83
	Silt	61.20	73.82	57.85
	Clay	36.72	23.67	41.32
	Texture	Silty clay loam	Silty loam	Silty clay
2.	Organic C (%)[2]	4.86 (high)	3.56 (high)	3.24 (high)
3.	Total N (%)[3]	0.28 (moderate)	0.24 (moderate)	0.32 (moderate)
4.	C/N	17 (high)	14 (moderate)	10 (low)
5.	$P_{Bray\ 1}$ (mg kg^{-1})[4]	3.51 (very low)	3.10 (very low)	9.22 (very low)
6.	P_2O_5 (mg kg^{-1})[5]	497 (high)	444 (high)	289 (moderate)
7.	K_2O (mg kg^{-1})[6]	876 (very high)	630 (very high)	357 (moderate)
8.	pH H_2O[7]	4.02 (very acidic)	4.28 (very acidic)	4.18 (very acidic)
9.	Exch.-Ca (cmol(+) kg^{-1})[8]	4.47 (low)	3.89 (low)	3.94 (low)
10.	Exch.-Mg (cmol(+) kg^{-1})[8]	5.48 (high)	6.63 (high)	6.05 (high)
11.	Exch.-Na (cmol(+) kg^{-1})[8]	0.04 (low)	1.34 (very high)	0.32 (moderate)
12.	Exch.-K (cmol(+) kg^{-1})[8]	0.25 (low)	0.32 (moderate)	0.09 (very low)
13.	KTK (cmol(+) kg^{-1})[9]	32.50 (high)	27.25 (high)	39.00 (high)
14.	Base saturation (%)	44 (moderate)	42 (moderate)	43 (moderate)
15.	EC (dS m^{-1})[10]	0.20	0.10	0.02
16.	Al saturation (%)[11]	2.15 (very low)	2.38 (very low)	0.50 (very low)

Note: *) Procedure of measurements are described in [1] Gee and Boulder (1986); McLean (1982); [2]Yeomans and Bremner (1988); [3]Bremner and Mulvaney (1982); [4]John (1970); [5]Olsen and Sommers (1982); [6]Knudsen *et al.* (1982); [7]McLean (1982); [8]Thomas (1982); [9]Rhoades (1982a); [10]Rhoades (1982b) ;[11]Exchangeable Al, Dougan and Wilson (1974). **)The values obtained were categorized as described in Djaenuddin *et al.* (1994).

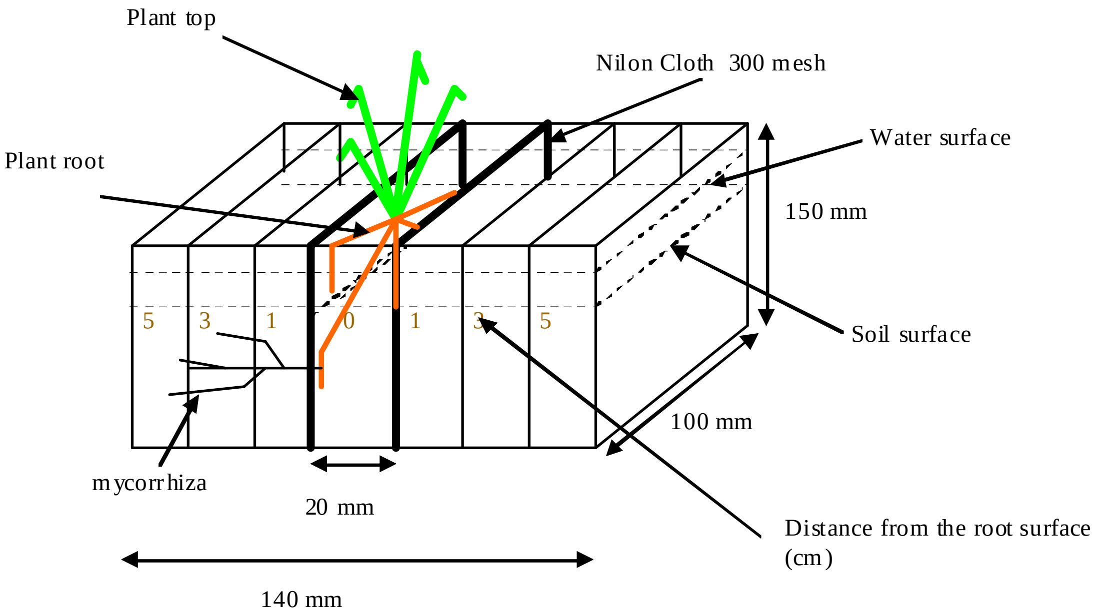

Figure 1. The layout of rhizobox.

Guntung Papuyu. The soils properties were shown in Table 1.

Rhizobox

The experiment was carried out in glass using a home-made rhizobox developed by (Wang *et al.* 2002). The rhizobox illustration can be seen in Figure 1. The nylon cloth used can not be penetrated by plant roots, however, mycorrhiza and water can be easily penetrate. The rice plants were grown in the middle segment of the rhizobox.

Treatments

The treatments of the experiment are shown in Table 2.

Rice Cultivation

Twenty rice seeds were sown at the middle segment of the rhizobox (see Figure 1) under saturated soil condition. At the 3rd day, seedlings were thinned to 10. The high plant density was deliberately done to create a rhizosphere soil and bigger impact of root on the soil. Seven days after emerging, the rhizobox was filled with deionized water to 1 cm depth and maintained till the end of growing period. To protect from pest attack the rhizoboxes were covered with a mosquito net. The plants were grown for 5 weeks.

Soil Sampling

One day before soil sampling, the watering was stopped to let the soil dried out. Each of soil segment

Tabel 2. Treatments for the rhizobox study.

Treatments *)	Notes		1	2	3
Soil origin:	Exchangeable Na	Clay content (%)			
• Kuin	low	37	√		
• Bunipah	Very high	24		√	
• Guntung Papuyu	moderate	41			√
Rice cultivars:					
• Padi Panjang	Extreme high yield local cultivar		√	√	√
• IR64	Improved cultivar, as a comparison		√	√	√

Note: *) each treatment was replicated 4 times.

from each rhizobox was excavated, put in a plastic bag and kept in a refrigerator (4°C) until used.

Soil Analysis

Soil analyses were conducted prior to planting and after the growing period. Soil analyses prior to planting were carried out for characterizing the soils used in the experiment. The soil properties used in this experiment are demonstrated in Table 1. At the end of growing period soil properties such as pH, Al, P, K, NH_4^+-N and NO_3^--N were analysed. Soil was extracted using a 0.01 *N* $CaCl_2$ according to methods described in Houba *et al*. (1994). The use of 0.01 *N* $CaCl_2$ is believed not only maintains the soil solution ionic strength but also is cheaper and environmental friendly. The pH, Al and P were determined using methods described in McLean (1982), Dougan and Wilson (1974) and John (1970), respectively. While, the NH_4^+ and NO_3^- concentration in the extract was measured colorimetrically using methods described in Kempers and Zweers (1986) and in Yang *et al.* (1998), respectively.

Data Analysis

Standard errors were shown to indicate data variation as affected by treatments set up.

RESULTS AND DISCUSSION

Soil Properties

The properties of soils are presented in Table 1. It is pointed out here that for growing improved rice cultivar there will be at least 2 problems faced. These are the low P availability and very low soil pH. In addition, unpredicted water level often submerges the newly planted seedlings. Nevertheless, the potential nutrients reserve such as N, P, and K are generally high.

It can also be observed that there were some differences among the soils. Firstly, the texture of soil from Guntung Papuyu was heavier than the other two soils. Next, the soil from Guntung Papuyu possessed highest C to N ratio, followed by soils from Bunipah and Kuin, respectively. Lastly, the Na^+ and K^+ concentrations and EC reading of soil from Bunipah

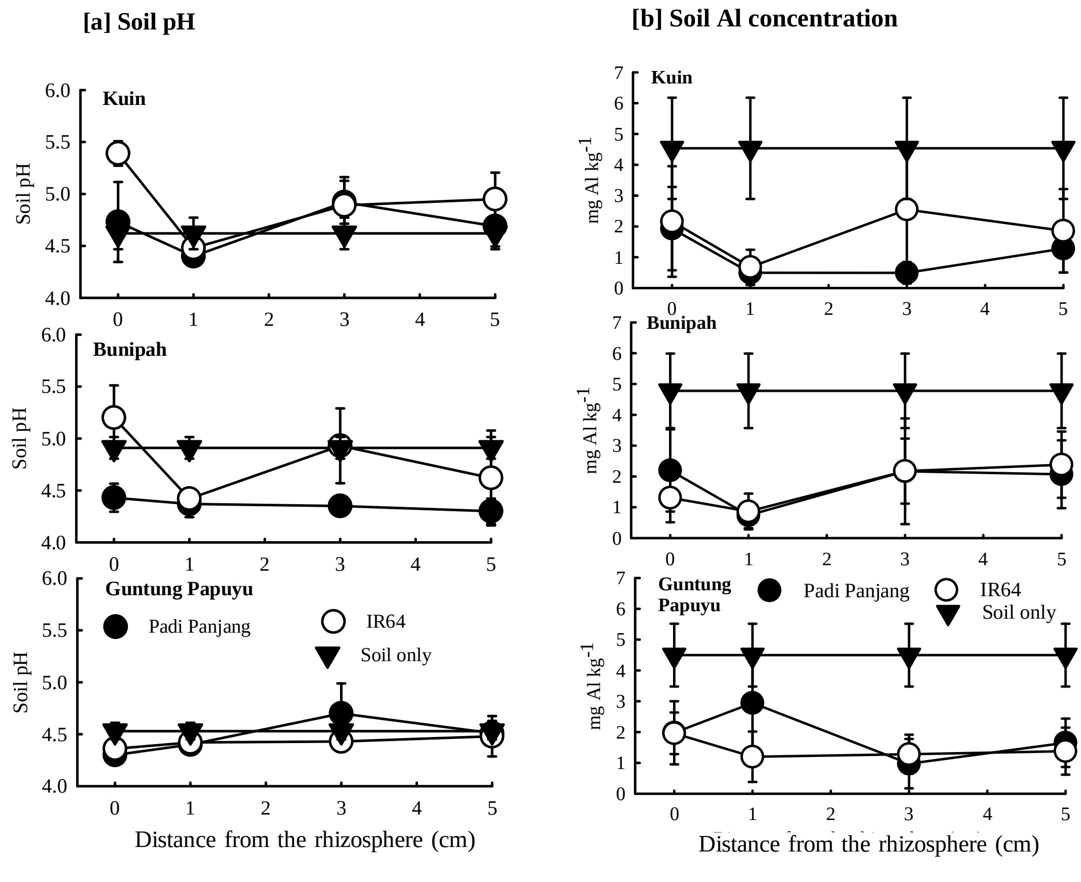

Figure 2. Change of soil pH (a) and soil Al concentration (b) at various distances from the rhizosphere. Bars indicate standard error of mean.

were higher than of soils from Kuin and Guntung Papuyu. It was noticed that Bunipah located near the river, therefore, it was highly affected saline water resulted from the tidal movement. These soil properties differences may contribute to the difference in magnitude affect of root on to the soil properties.

Change in Soil pH

Figure 2a shows the change of soil pH from various distances from the rhizophere. Except soil from Guntung Papuyu, pH rhizophere soil of Padi Panjang cultivar was lower than of IR64 cultivar. Even, in soil from Bunipah, root of Padi Panjang cultivar acidified the soil more than to the control soil without plant. The lower soil pH in the rhizosphere of Padi Panjang cultivar may be explained as follow. Purnomo *et al*. (2005) observed that compared to IR64 cultivar, Padi Panjang cultivar had a larger rooting system. In addition, our unpublished data showed that Padi Panjang cultivar had much higher biomass compared to IR64 cultivar. So, it may be plausible that the root of Padi Panjang cultivar (1) releases more soluble organic acid, (2) has more oxidative condition in the rhizosphere results in the oxidation of potential acidic materials, namely, soluble iron Fe^{2+}, (Saleque and Kirk, 1995), mangan (Mn^{2+}) and/or sulphur (S^0), and (3) takes up more cations than anions, therefore, H^+ is released by the root for maintaining neutrality of electricity charge of soil interface (Grinsted *et al*. 1982; Begg *et al*. 1994).

Change in Soil Al Concentration

For all soils, the Al concentration in soil grown with plant was lower compare with control soil without plant (Figure 2b). It was mentioned earlier that the release of exudates from the root may chelate the Al in the soil solution. The release of exudates decreased the Al concentration as far as 5 cm from the rhizosphere.

Change in Soil P Concentration

It can be observed that P concentration in rhizophere of Padi Panjang cultivar was higher than

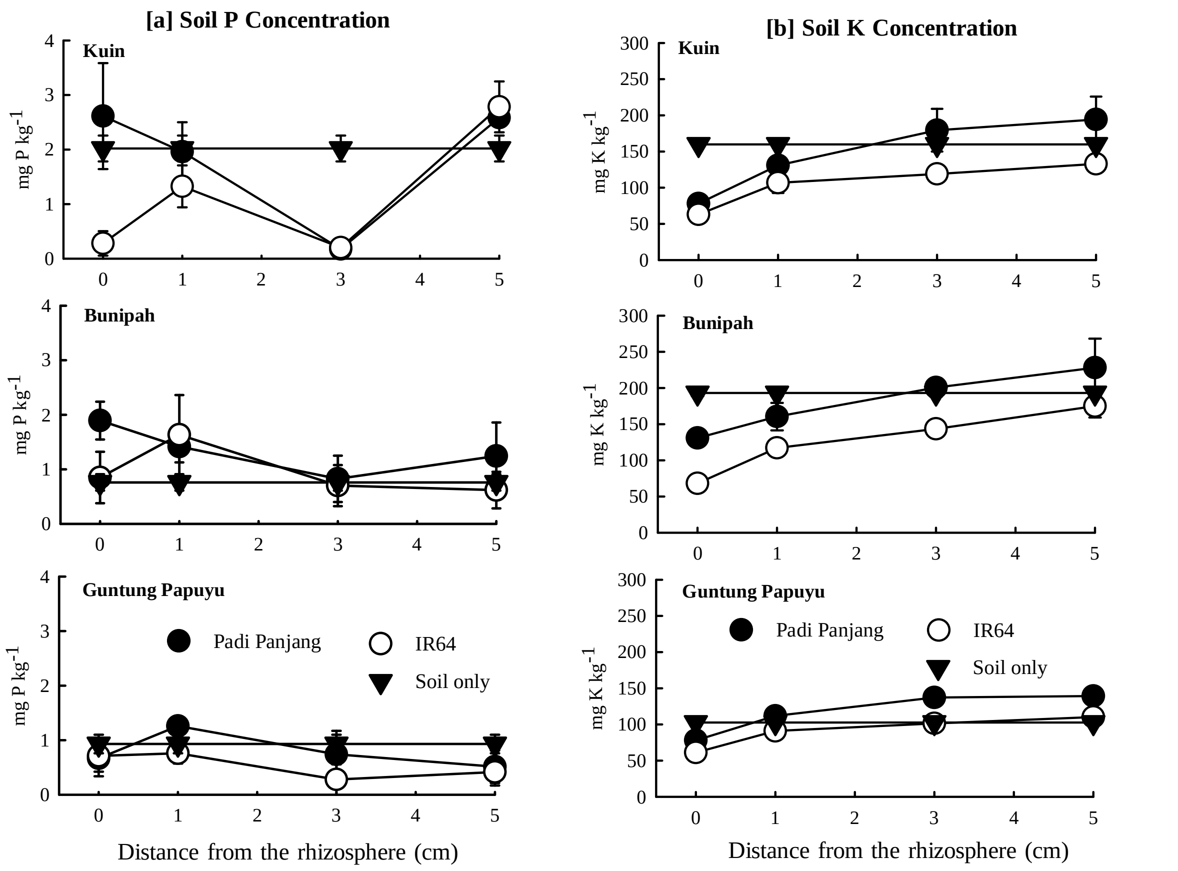

Figure 3. Change of soil P (a) and soil K (b) concentrations at various distances from the rhizosphere. Bars indicate standard error of mean.

of IR64 cultivar grown in soils from Kuin and Bunipah (Figure 3a). For IR64 cultivar, a depletion zone was noticed, especially for soil for Kuin. The P concentration in the soil rhizosphere was lower than soil outside the rhizosphere. Some works have shown a similar phenomenon occurred with maize (Gahoonia *et al*. 1994), white clover (Li *et al*. 1991) and a model developed by Luster *et al.* (2009).

For Padi Panjang, however, no depletion zone was observed. The P concentration was higher than in the rhizosphere of IR64 cultivar. In Kuin's soil, the P concentration of the rhizosphere soil was the same as of the soil only. Even, in Bunipah's soil, the P concentration of the rhizosphere soil was higher than of the soil only. Using different plant *Brassica napus* (Grinsted *et al*. 1982) found an increase in P concentration in the soil rhizosphere as a result of pH decrease. They suggested that *Brassica napus* is efficient in absorbing P from P-deficient. It may reasonable to consider that Padi Panjang cultivar is efficient in absorbing P. It was also observed that the root of rice affected the P concentration as far as 3 cm.

Changes in Soil K^+ Concentration

Figure 3b shows the concentration of K at various distances from the rhizosphere. Different from P, it was observed the patterns of K concentration were similar for both rice cultivars, being lower in the soil rhizosphere and increasing as moving away from the rhizophere. As with P, a depletion zone was also observed for K. Using rice plant, Li *et al*. (2002) also found a similar result. The present works showed that the depletion zone could be noticed up to 3 cm. Our results demonstrated K concentration in soil grown with Padi Panjang cultivar higher than in soil grown with IR64. This may be associated with the lower pH as result of exudates release that may dissolve the reserved K. The effect of exudates in dissolving the reserve K can reach up to 5 cm from the rhizosphere.

Change in Soil NH_4^+ Concentration

The patterns of NH_4^+ change for all soils were similar for both rice cultivars (Figure 4a). As for P and K, a depletion zone was also noticed. Comparing

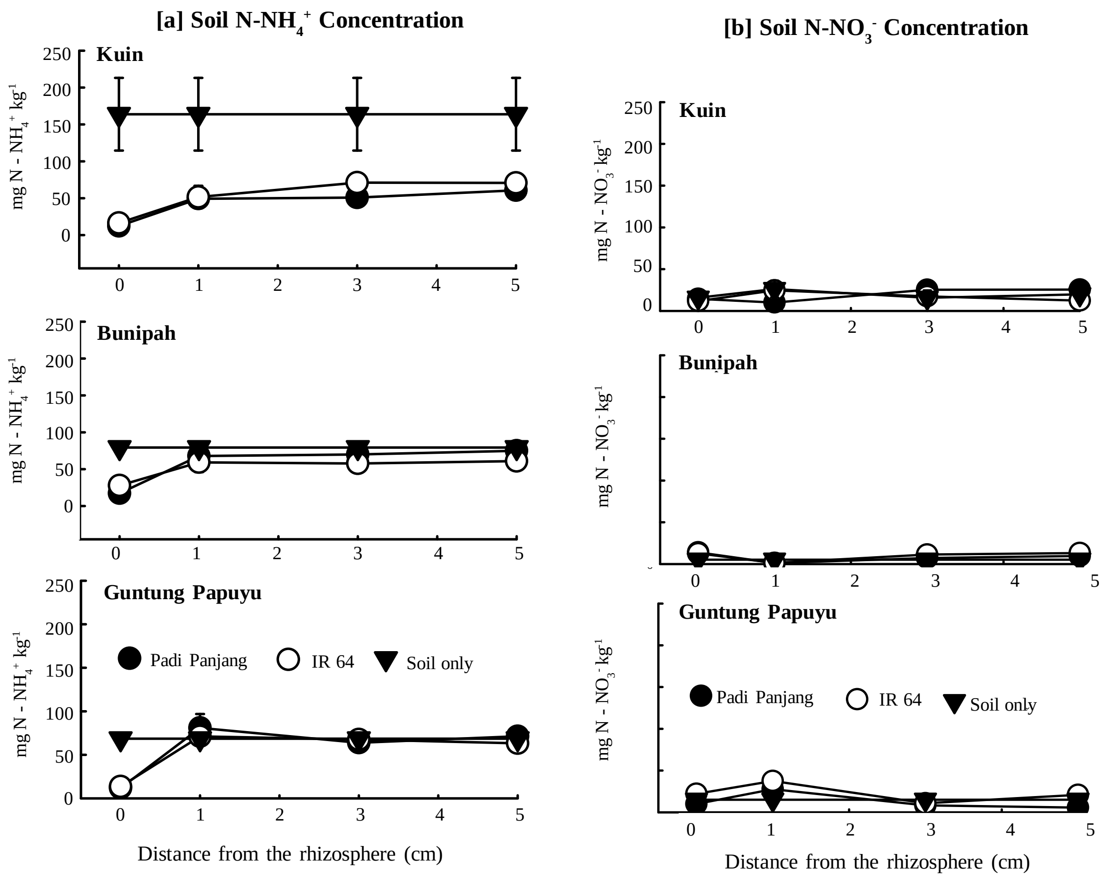

Figure 4. Changes in (a) soil N-NH_4^+ and (b) soil N-NO_3^- concentrations at various distances from the rhizosphere. Bars indicate the standard error of mean.

with soil only, NH_4^+ concentration of soil with plant was lower. The NH_4^+ concentrations were similar for Padi Panjang and IR64 cultivars. It was also observed that limit of NH_4^+ could be absorbed that was approximately 50-55 mg NH_4^+-N kg^{-1}. It is suggested that only free soluble NH_4^+ could have been absorbed by the plant.

Changes in Soil NO_3^- Concentration

The change of NO_3^- was less extent compared to NH_4^+. The change of NO_3^- at various distances from the rhizophere was hardly notice (Figure 4b). It is common that in submerged soil nitrification process is inhibited (Purnomo 1996). The similarity of NO_3^- concentration in the planted soil and soil only suggested that NH_4^+ was the main source of N for the rice crops in the current study.

CONCLUSIONS

The Padi Panjang cultivar had the capability to change the soil chemical properties in the rhizophere. The impact was more extent compared with IR64 cultivar. The changes were depended on soil character, especially, soil texture. Soil from Guntung Papuyu was the least affected by root. It was showed that Padi Panjang cultivar acidified more than IR64. A depletion zone of K and NH_4^+ was found in the rhizosphere of both Padi Panjang and IR64 cultivars. The depletion zone could reach as far as 3 cm from the rhizosphere. For P, the depletion zone only occurred in the rhizosphere soil of IR64 cultivar. However, for Padi Panjang cultivar, the depletion zone of P did not exist. The Padi Panjang cultivar was able to maintain P concentration the same as or higher than control soil without plant. It is the first report showed that Padi Panjang cultivar can be considered as efficient lowland rice in absorbing not only P but also K in a P- and K-deficient-soil.

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