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 rhizosphere 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 (NH₄⁺), and nitrate (NO₃⁻) 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 NH₄⁺ 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 Guntung Papuyu. The properties of these soils are summarized in Table 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Soil Properties$^*$</th>
<th>Soil origin$^{**}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Kuin (3°22'24''S; 114°32'19''E)</td>
</tr>
<tr>
<td>1.</td>
<td>Particle size analysis (%)$^3$</td>
<td>Sand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silt</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clay</td>
</tr>
<tr>
<td></td>
<td>Texture</td>
<td>Silty clay loam</td>
</tr>
<tr>
<td>2.</td>
<td>Organic C (%)$^2$</td>
<td>(high)</td>
</tr>
<tr>
<td>3.</td>
<td>Total N (%)$^1$</td>
<td>(moderate)</td>
</tr>
<tr>
<td>4.</td>
<td>C/N</td>
<td>(high)</td>
</tr>
<tr>
<td>5.</td>
<td>$P_{\text{illay}}$ (mg kg$^{-1}$)$^4$</td>
<td>(very low)</td>
</tr>
<tr>
<td>6.</td>
<td>$P_2O_5$ (mg kg$^{-1}$)$^5$</td>
<td>(high)</td>
</tr>
<tr>
<td>7.</td>
<td>$K_2O$ (mg kg$^{-1}$)$^6$</td>
<td>(very high)</td>
</tr>
<tr>
<td>8.</td>
<td>pH H$_2$O$^7$</td>
<td>(very acidic)</td>
</tr>
<tr>
<td>9.</td>
<td>Exch.-Ca (cmol(+)/kg$^{-1}$)$^8$</td>
<td>(low)</td>
</tr>
<tr>
<td>10.</td>
<td>Exch.-Mg (cmol(+)/kg$^{-1}$)$^8$</td>
<td>(high)</td>
</tr>
<tr>
<td>11.</td>
<td>Exch.-Na (cmol(+)/kg$^{-1}$)$^8$</td>
<td>(low)</td>
</tr>
<tr>
<td>12.</td>
<td>Exch.-K (cmol(+)/kg$^{-1}$)$^8$</td>
<td>(low)</td>
</tr>
<tr>
<td>13.</td>
<td>KTK (cmol(+)/kg$^{-1}$)$^9$</td>
<td>(high)</td>
</tr>
<tr>
<td>14.</td>
<td>Base saturation (%)</td>
<td>(moderate)</td>
</tr>
<tr>
<td>15.</td>
<td>EC (dS m$^{-1}$)$^{10}$</td>
<td>(very low)</td>
</tr>
<tr>
<td>16.</td>
<td>Al saturation (%)$^{11}$</td>
<td>(very low)</td>
</tr>
</tbody>
</table>

Note: $^1$Procedure of measurements are described in 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).
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.

![Figure 1. The layout of rhizobox.](image)

**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

<table>
<thead>
<tr>
<th>Treatments *)</th>
<th>Notes</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil origin:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Kuin</td>
<td>Exchangeable Na</td>
<td>low</td>
<td>37</td>
<td>✓</td>
</tr>
<tr>
<td>• Bunipah</td>
<td>Clay content (%)</td>
<td>Very high</td>
<td>24</td>
<td>✓</td>
</tr>
<tr>
<td>• Guntung Papuyu</td>
<td></td>
<td>moderate</td>
<td>41</td>
<td>✓</td>
</tr>
<tr>
<td>Rice cultivars:</td>
<td></td>
<td>Extreme high yield local cultivar</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>• Padi Panjang</td>
<td></td>
<td>Improved cultivar, as a comparison</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

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, NH₄⁺-N and NO₃⁻-N were analysed. Soil was extracted using a 0.01 N CaCl₂ according to methods described in Houba et al. (1994). The use of 0.01 N CaCl₂ is believed not only maintains the soil solution ionic strength but also is cheaper and environmentally friendly. The pH, Al and P were determined using methods described in McLean (1982), Dougan and Wilson (1974) and John (1970), respectively. While, the NH₄⁺ and NO₃⁻ concentration in the extract was measured colorimetrically using methods described in Kempers and Zweers (1986) and in Yang et al. (1998), respectively.

**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.](image-url)
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 rhizosphere. Except soil from Guntung Papuyu, pH rhizosphere 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 rhizosphere of Padi Panjang cultivar was higher than
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 rhizosphere. 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 reserve K. The effect of exudates in dissolving the reserve K can reach up to 5 cm from the rhizosphere.

Change in Soil NH₄⁺ Concentration

The patterns of NH₄⁺ change for all soils were similar for both rice cultivars (Figure 4a). As for P and K, a depletion zone was also noticed. Comparing
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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REFERENCES


Houba VJG, I Novozamsky and E Temminghoff. 1994. Soil Analysis Procedures Extraction with 0.01 M CaCl$_2$ (Soil and Plant Analysis, Part 5A). Department of Soil Science and Plant Nutrition, Wageningen Agricultural University. The Netherlands.

Kempers AJ and A Zweers. 1986. Ammonium
determination in soil extract by the salicylate method.

Knudsen D, GA Peterson and PF Prafit. 1982. Lithium,
sodium and potassium. In: AL Page, RH Miller and
DR Keeney (eds), Methods of Soil Analysis II,
Chemical and Microbiological Properties, 2nd edition.
ASA, Madison, WI, pp. 225-246.

Li H, X Yang, GJD Kirk and A Dobbermann 2002. Root-
induced of potassium in the rhizosphere of lowland
rice (Oryza sativa L.) 17th WCSS, 14-21 August 2002,
Thailand.

Li X-L, E George and H Marschner. 1991. Phosphorus
depletion and pH decrease at the root-soil and
hyphae-soil interfaces of VA Mycorrhizal White
Clover fertilized with ammonium. New Phytol
119: 397-404.

Sampling, defining, characterising, and modelling the
rhizosphere-the soil science tool box. Plant Soil
321: 457-482.

Page, RH Miller and DR Keeney (eds), Methods of
Soil Analysis. II. Chemical and Microbiological
Properties, 2nd edition. ASA, Madison, Wisconsin, pp
199-224.

Page, RH Miller and DR Keeney (eds), Methods of
Soil Analysis II, Chemical and Microbiological
Properties, 2nd edition. ASA, Madison, Wisconsin, pp:
403-430.

Purnomo E. 1996. Mineralisation and nitrification of soil
University. Wagga, NSW.

Purnomo E, M Sarwani, A Jumberi, A Mursyid, T
Hasegawa, Y Hashidoko, T Shinano, S Honma and
Local Rice Varieties Grown without Fertilizer on

Purnomo E, Y Hashidoko, T Hasegawa and M Osaki. 2010.
Extreme high yield of tropical rice grown without
fertilizer on acid sulfate soil in South Kalimantan,

Rhoades JD. 1982a. Cation exchange capacity. In: AL Page,
RH Miller and DR Keeney (eds), Methods of Soil
Analysis II, Chemical and Microbiological Properties,
2nd edition. ASA, Madison, WI, pp. 149-158.

Rhoades JD. 1982b. Soluble salts. In: AL Page, RH Miller
and DR Keeney (eds), Methods of Soil Analysis II,
Chemical and Microbiological Properties, 2nd edition.
ASA, Madison, WI, pp. 167-180.

Saleque MA. and GJD. Kirk 1995. Root-induced
solubilisation of phosphate in the rhizosphere of

Thomas GW. 1982. Exchangeable cations. In: AL Page,
RH Miller and DR Keeney (eds), Methods of Soil
Analysis II, Chemical and Microbiological Properties,
2nd edition. ASA, Madison, WI, pp. 159-166.

Yanai RD, H Majdi and BB Park. 2003. Measured and
modelled differences in nutrient concentrations
between rhizosphere and bulk soil in a Norway spruce

spectrophotometric determination of nitrate in water,

Yeomans JC and JM Bremner. 1988. A rapid and precise
method for routine determination of organic carbon