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Root Penetration Ability of Vietnamese Traditional Upland Rice Varieties

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Drought is the major cause of low yield of rice grown in the rainfed uplands, where has aerobic and strong soil because of water deficit. Root penetration ability (RPA) through compacted soil layers or hardpans has been recognized as an important breeding objective for improvement of drought resistance in rice. The study was conducted to evaluate RPA of Vietnamese traditional upland rice varieties comparing with rice cultivars belonged to different ecotypes. Root penetration ability was evaluated through shallow (5 cm) and deep (10 cm) wax layers in the plastic tube. Root penetration rate (RPR), that is the ratio of the number of roots penetrated wax layers (PRN) to the total number of roots (TRN), was assumed to be an index of PRA. Although RPR through shallow wax layer was higher than that through deep wax layer, higher correlation between them was found ($r = 79^{**}$). Japonica upland showed the superior RPA than other ecotypes. While, there was no significant difference between RPR of Vietnamese traditional upland and other Indica upland rice. Significant correlations between RPR and TRN, PRN, root thickness (RT) and root dry weight (RDW) in deep wax layers treatment were found ($r = -0.41^{**}$, $r = 0.82^{**}$, $r = 0.63^{**}$, and $r = 0.51^{**}$, respectively).

INTRODUCTION

The world's annual cultivating area of rice is about 148 million ha, of which about 12% is rainfed upland (Khush, 1997). Although the production of upland rice is important to the agricultural economy of many countries, upland rice contributes only 4% of the total rice production, because of its low yield with an average 1 ton ha⁻¹ (Dat, 1986). Also in Vietnam, upland rice is now still grown on about 0.45 million ha (Hong *et al.*, 1999), and is commonly cultivated as shifting cultivation, and slash and burn occupied practice by the ethnic minority who lived in the mountainous area. There are many traditional upland rice varieties cultivated in this area, but the yield varied from 0.6 to 2.0 tons ha⁻¹ (Hong *et al.*, 1999).

Drought stress is a major constraint to the productivity of rice in upland ecosystem (Nguyen *et al.*, 1997). In these areas, soils are commonly aerobic and may be strong due to lack of water. Strong soil causes a serious problem in crop production, because it restrict access of the root system to water and nutrient, and so decrease crop yield (Clark *et al.*, 2003). Rice plant with a deep root system is therefore beneficial in avoiding water stress by absorbing water from deep soil layers (Clark *et al.*, 2002). Root penetration ability (RPA) through compacted soil layers or hardpans has been recognized as an important breeding objective for improvement of drought resistance in rice (Hanson *et al.*, 1990)

For screening root traits in rice, several techniques in laboratory have been developed. The method using thin wax layers instead of soil hardpans for measuring RPA was proposed by Yu *et al.* (1995). They found that upland rice varieties showed better RPA than lowland varieties. This method was subsequently used by many researchers (Ali *et al.*, 2000; Babu *et al.*, 2003; Price *et al.*, 2000; Ray *et al.*, 1996; Zheng *et al.*, 2000) to identify QTLs controlling RPA. Kubo *et al.* (2004) modified the method that is 3 mm wax layer was installed at 10 cm of Polyvinyl Chloride (PVC) tube (6 cm diameter and 15 cm height) filled with vermiculite to assess RPA of a recombinant inbred line in wheat (*Triticum turgidum* L. var. *durum*). This method is considered easier to investigate RPA of rice.

Assessment of huge genotypic difference on RPA and root traits is an initial step to breed new rice variety with drought resistance. This study was therefore conducted to evaluate RPA of Vietnamese traditional upland rice varieties comparing with rice cultivars belonged to other groups.

MATERIALS AND METHODS

This study was conducted in the phytotron of Kyushu University from July to September, 2005.

Experiment 1. The relations between the hardness of wax layers and the RPA

Six rice varieties were used to test for the RPA through wax layers with different hardness. Beo dien and Ep hat dai are Vietnamese traditional upland, Sensho and Hataminori Mochi are Japonica upland, and Nipponbare and Koshihikari are Japonica lowland rice varieties.

Wax layers with different strength were made by

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mixing paraffin and vaseline in different proportions. The mixture of each six paraffin concentrations (30, 40, 50, 60, 70 and 80%) and vaseline was well blended. The mixture was heated at 80 °C until the wax was completely melted, and then poured into PVC tubes (height: 70 mm or 3 mm; diameter: 6 cm), and allowed to solidify at room temperature. Mechanical strength of wax layers which 70 mm of height were measured by using the soil penetrometer (DIK-5561, Daikirikakogyo Co., Ltd. Tokyo, Japan) at 25 °C.

Wax layers (3 mm thick and 6 cm in diameter) of each formula were installed at 10 cm from the top of PVC tube (15 cm height and 6 cm in diameter). The gaps between wax layers and the side of the tube were sealed by melted wax. The spaces in the tube are filled with nutrient vermiculite and watered. The tubes were covered at the bottom with plastic screen mesh (1 mm spacing) therefore vermiculite could be held inside of the tubes. Chemical fertilizer (4% NH₄; 4% P₂O₅; 2.5% MgPO₄; 4% K₂O) was applied with 0.73 g per tube. All tubes were placed in the water bath (1 m × 0.9 m × 0.3 m) and the water surface was maintained at a level just below the position of the wax layers. Seeds of all varieties were soaked in water at 30 °C for 3 days. A

single seed of each variety was sown per tube. Plants were grown in the growth cabinet at 25 °C, 70% relative humidity and 250–300 μmol m⁻² s⁻¹ light intensity for 12 h day⁻¹, and were watered every three days.

At 21 days after sowing (DAS), the total number of roots (TRN) and the number of roots that penetrated the wax layer (PRN) in each plant was counted. The root penetration rate (RPR) indicating the RPA was calculated as the ratio of PRN to TRN.

Experiment 2. Varietal difference of the RPA

Seventy two rice including 6 varieties used in Exp.1 were tested. Of which, 23 were Vietnamese traditional upland, 13 were Japonica upland, and 17 were Japonica lowland rice varieties. The remaining were 19 Indica upland rice varieties collected from IRRI and several other countries (Table 1).

A wax of 60% paraffin (penetrometer resistance was 1.5 MPa) was used in this experiment. The wax layers were installed in tube (15 cm height, and 6 cm in diameter) from the top at 5 cm and 10 cm in the shallow and the deep hardpan treatment, respectively. The screening system was prepared as described detail in the Exp.1.

Table 1. Plant materials

Name	Origin	Cultural type	Variety type	Name	Origin	Cultural type	Variety type
Beo dien	Vietnam	Upland	Traditional indica	LC-90-12	IRRI	Upland	Indica
Beo san van	Vietnam	Upland	Traditional indica	LP93-1	IRRI	Upland	Indica
Do meo	Vietnam	Upland	Traditional indica	UPLR1-7	IRRI	Upland	Indica
Ep hat dai	Vietnam	Upland	Traditional indica	WAB 96-1-1	IRRI	Upland	Indica
Ep hat den	Vietnam	Upland	Traditional indica	63-104	Ivory cost	Upland	Indica
Ep hat to	Vietnam	Upland	Traditional indica	8 FA337-1	IRRI	Upland	Indica
Ep hat tron	Vietnam	Upland	Traditional indica	Azucena	Philippines	Upland	Japonica
Khau kai	Vietnam	Upland	Traditional indica	Hataminori Mochi	Japan	Upland	Japonica
Khau ken	Vietnam	Upland	Traditional indica	Minamihata Mochi	Japan	Upland	Japonica
Khau linh	Vietnam	Upland	Traditional indica	Owarihata Mochi	Japan	Upland	Japonica
Khau van	Vietnam	Upland	Traditional indica	Rikuto Norin 6	Japan	Upland	Japonica
Mo do	Vietnam	Upland	Traditional indica	Rikuto Norin 12	Japan	Upland	Japonica
Mua chua	Vietnam	Upland	Traditional indica	Rikuto Norin 22	Japan	Upland	Japonica
Nep bao lac	Vietnam	Upland	Traditional indica	Rikuto Norin 24	Japan	Upland	Japonica
Nep ha giang	Vietnam	Upland	Traditional indica	Rikuto Norin Mochi 1	Japan	Upland	Japonica
Nep khau non	Vietnam	Upland	Traditional indica	Rikuto Norin Mochi 8	Japan	Upland	Japonica
Nep meo	Vietnam	Upland	Traditional indica	Rikuto Norin Mochi 18	Japan	Upland	Japonica
Nep nuong trang	Vietnam	Upland	Traditional indica	Rikuto Norin Mochi 20	Japan	Upland	Japonica
Nep xiem	Vietnam	Upland	Traditional indica	Rikuto Norin Mochi 25	Japan	Upland	Japonica
Ple chong po	Vietnam	Upland	Traditional indica	Akebono	Japan	Lowland	Japonica
Thoc te duoi bo	Vietnam	Upland	Traditional indica	Chiyonishiki	Japan	Lowland	Japonica
Vien cham	Vietnam	Upland	Traditional indica	Sekisho	Japan	Lowland	Japonica
Xe liem	Vietnam	Upland	Traditional indica	Toyonishiki	Japan	Lowland	Japonica
Columbial	Colombia	Upland	Indica	Domannaka	Japan	Lowland	Japonica
Khao Dam	Laos	Upland	Indica	Haenuki	Japan	Lowland	Japonica
Kinandang Patong	Philippines	Upland	Indica	Miyazaki Zairai	Japan	Lowland	Japonica
Ma Hae	Thailand	Upland	Indica	Aikoku	Japan	Lowland	Japonica
Sensho	Japan	Upland	Indica	Akitsuhoh	Japan	Lowland	Japonica
CI PAD141	IRRI	Upland	Indica	Hinohikari	Japan	Lowland	Japonica
CT6510-24-1-2	IRRI	Upland	Indica	Kibinohana	Japan	Lowland	Japonica
Dourado Precode	Brazil	Upland	Indica	Lemont	Japan	Lowland	Japonica
IR47686-30-3-2	IRRI	Upland	Indica	Takara	Japan	Lowland	Japonica
IR57920	IRRI	Upland	Indica	Koshihikari	Japan	Lowland	Japonica
IR715-19-1-1	IRRI	Upland	Indica	Shirobeniya	Japan	Lowland	Japonica
IRAT 117	Ivory cost	Upland	Indica	Shinriki	Japan	Lowland	Japonica
LAC23	Liberia	Upland	Indica	Nipponbare	Japan	Lowland	Japonica

The data of the TRN, PRN, were recorded at 21 DAS, and the RPR was calculated. Three penetrated roots were randomly collected from each plant for root thickness (RT) measurement. Root thickness was measured at 1 cm from the root tip. Root dry weight (RDW) was measured after drying at 70 °C for 72 hours.

Each experiment was conducted in randomized complete block designed with 3 replications. Data were analyzed with the statistical procedure of SAS (SAS Institute, Cary, NC). Analysis of variance was performed with the PROC ANOVA procedure and correlations were obtained with the PROC CORR procedure (Pearson correlations).

RESULTS

Penetrometer resistance of wax layers

The strength of various wax layers was showed in Fig. 1. Penetrometer resistance increased with the percentage of paraffin in the wax layers, reaching 4.5MPa at 80% paraffin concentration of wax layer.

Effect of wax layer strength to RPR

Fig. 2 showed that RPR of every variety used decreased as the hardness of wax layer increased. There was no variety that penetrated the wax layer of 70%. Varietal differences were detected at every hardness of wax layers except 70% paraffin. RPR of Sensho and Hataminori Mochi were 37.3 and 32.9%, respectively, while that of the others ranged from 8.4 to 16.8% at the wax layer of 60% paraffin.

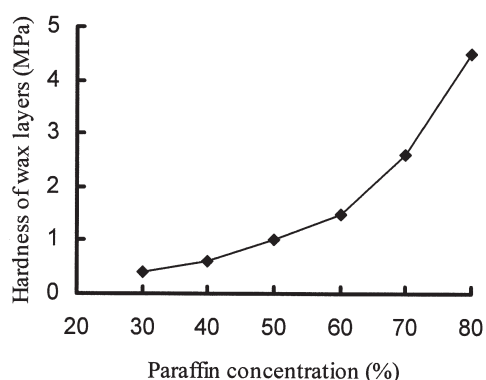


Fig. 1. Effect of paraffin concentration on hardness of wax layers.

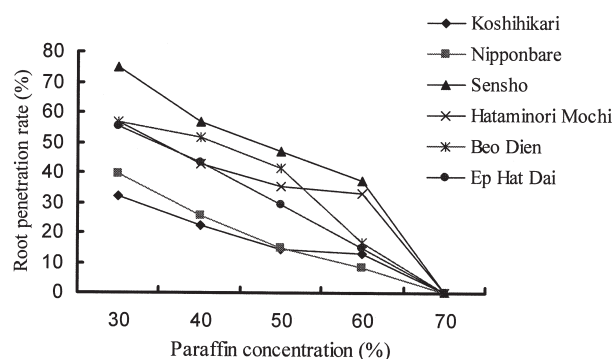


Fig. 2. Effect of paraffin concentration to the root penetration rate in rice.

Varietal differences of root penetration ability and some root traits.

The mean value of 4 rice groups on the root traits in both shallow and deep hardpan treatment are summarized in Table 2. Variation on all root traits was found between 4 groups. Japonica lowland had the highest TRN both in shallow hardpans (TRNS) and deep hardpans (TRND) with means of 28.5 and 30.3, respectively. The lowest mean value of TRNS and TRND were found in Indica upland (18.7) and Vietnamese traditional upland (20.9), respectively. PRN through shallow hardpans (PRNS) and PRN through deep hardpans (PRND) of Japonica upland group were higher than the others with mean of 6.3 and 6.7, respectively. Japonica upland had both the highest RPR through shallow hardpan (RPRS) of 31.7 and RPR through deep hardpan (RPRD) of 28.2. The lowest of these values were found in Japonica lowland with 18.6 of RPRS and 10.4 of RPRD, respectively. In all upland groups RT were 2-fold bigger than that in lowland rice. Japonica, Vietnamese traditional, and Indica upland had 0.71, 0.73 and 0.71 mm of RT, respectively. While, Japonica lowland had 0.36 of RT. Japonica upland rice had the highest RDW (0.11) and the lowest (0.06) was found in Japonica lowland.

In all groups the relationship between RPR through shallow and deep hardpan were found a positive significant correlation coefficient with $r = 0.79^{**}$ (Fig. 3).

Relations between RPR and other root traits in deep hardpan treatment were given in the Fig. 4. RPR positively correlated with PRN, RT, and RDW, but negatively associated with TRN. The correlation coefficient of TRN, PRN, RT and RDW with RPRD were $r = -0.41^{**}$, $r = 0.82^{**}$, $r = 0.63^{**}$ and $r = 0.51^{**}$, respectively.

Table 2. Variation on root traits among 4 varietal groups¹

Group	TRNS	PRNS	%			mm			RDWD
			RPRS	TRND	PRND	RPRD	RTD		
Japonica upland	20.2 c	6.3 a	31.7 a	24.5 b	6.7 a	28.2 a	0.71 a	0.11 a	
Vietnamese traditional upland	22.2 b	5.6 b	26.1 b	20.9 d	4.3 b	20.5 b	0.73 a	0.10 b	
Indica upland	18.7 c	4.9 c	26.6 b	22.4 c	4.0 b	19.3 b	0.71 a	0.10 b	
Japonica lowland	28.5 a	5.2 bc	18.6 c	30.3 a	3.1 c	10.4 c	0.36 b	0.06 c	

TRNS, PRNS and RPRS: total root number, penetrated root number and root penetration rate through shallow wax layers, respectively. TRND, PRND, RPRD, RTD and RDWD: total root number, penetrated root number, root penetration rate, root thickness and root dry weight through deep wax layers, respectively. ¹Means with the same letter in a column are not significant.

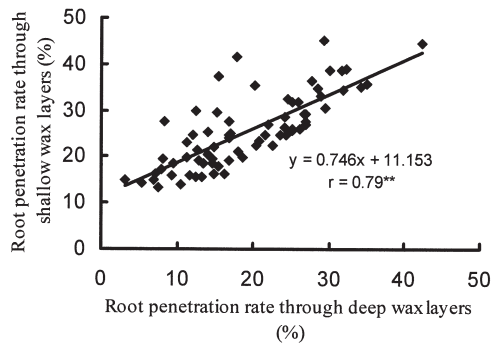


Fig. 3. Relationship between root penetration rate through shallow and deep wax layers; ** Significant at $P = 0.01$.

DISCUSSION

So far, many experiments have been suggested that the ability of rice to penetrate compacted soil is linked with capacity to develop several root traits such as: few thick (fibrous), long root axes, and root biomass (Babu *et al.*, 2001; Ekanayake *et al.*, 1985; Samson *et al.*, 2002; Yu *et al.*, 1995). However, in laboratory the effect of hardpan position to root penetration in rice has not been reported. In this study, two treatments of hardpan position (at 5 and 10 cm) from the soil surface were conducted to screen RPA in rice cultivars. Although the RPR through shallow hardpan was higher than that through deep hardpan (Table 3), there was a positive correlation coefficient between them (Fig. 3). In both treatments, RPRS and RPRD were highest in Japonica upland and lowest in Japonica lowland. There was no

significant difference between those in Indica and Vietnamese traditional upland. In general, RPR of rice was highly associated with the PRN (Babu *et al.*, 2001) as it also found in this study. Japonica upland usually had superior root traits than the other rice ecotypes (Yu *et al.*, 1995 and Babu *et al.*, 2001).

Genotypic variation of root morphology has been reported (Babu *et al.*, 2001; Thanh *et al.*, 1999; Yu *et al.*, 1995). Yu *et al.* (1995) suggested there was a significant genotypic variation existed on RPA among rice cultivars. They indicated that upland-adapted Japonica varieties had higher root penetration index than the lowland-adapted Indica varieties. In general, Japonica adapted-upland and traditional-upland rice cultivars have well developed root system with inherent higher RPA (Thanh *et al.*, 1999; Yoshida, 1982; Yu *et al.*, 1995). However, Babu *et al.* (2001) reported that an Indica accession (IR 58821-23-B-1-2-1) and traditional varieties (Kallurundaikar and Norungan) had higher penetration index, than even Japonica accessions in their experiment.

Root penetration through compacted soil layers or hardpans has been recognized as an important breeding objective for improvement of drought resistance in rice (Hanson *et al.*, 1990). As observed in this research, Japonica upland had higher RPR than other rice groups (Table 2). Japonica lowland had higher TRN, however they showed weak RPR. It was suggested that greater TRN did not contribute to the ability of rice roots to penetrate compacted soil as described by Babu *et al.* (2001) and Nguyen *et al.* (1997).

Rice varieties which had thick root could penetrate compacted soil to reach the water in depth (Ekanayake *et al.*, 1985; Veen, 1982; Yoshida, 1982; Yu *et al.*, 1995).

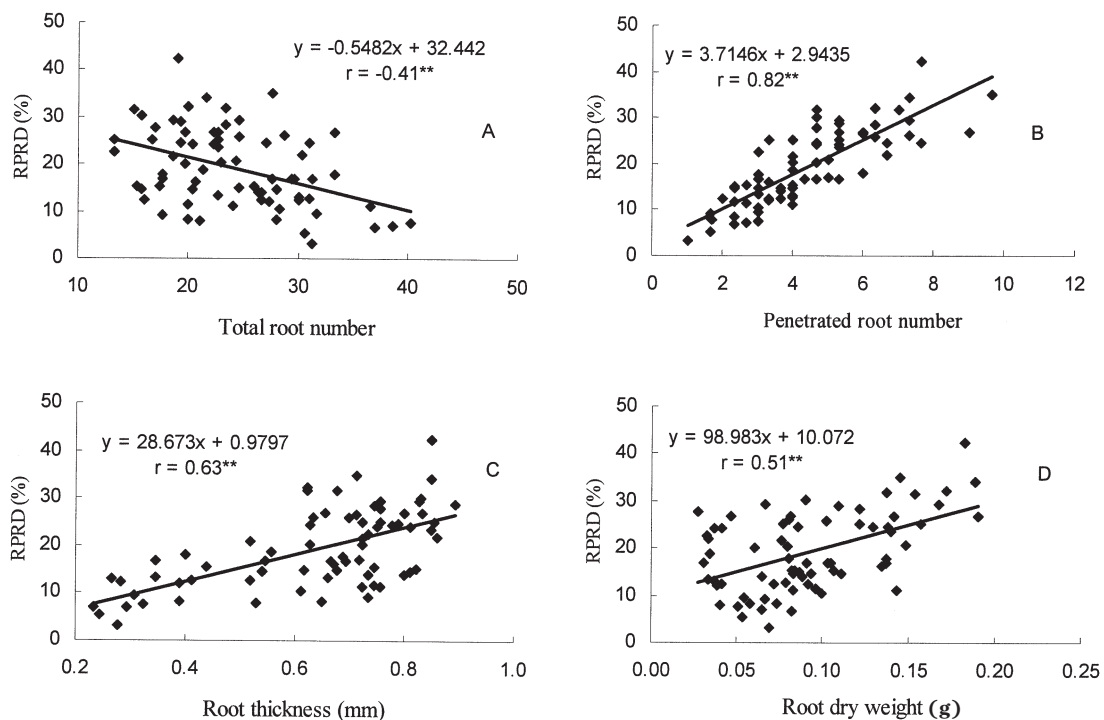


Fig. 4. Relationship between root penetration rate through deep wax layers and: A. Total root number; B. Penetrated root number; C. Root thickness; D. Root dry weight. ** Significant at $P = 0.01$.

In our study, all upland rice groups had superior root thickness value than lowland rice (Table 2). There was a positive correlation coefficient between RTD and RPRD (Fig. 4). Babu *et al.* (2001) reported that root biomass was a good indicator of drought avoidance in upland rice. Our result revealed that the RDW of upland rice was higher than that of lowland rice (Table 2). Further the positive correlation coefficient between RDW and RPRD was found.

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