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Relationship between Vertical Root Distribution and Yield Traits in IRRI's New Plant Type Rice

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ABSTRACT

This experiment was conducted to elucidate the relationship between vertical distribution of rice roots and yield traits under field conditions. Eight IRRI's new plant type rices (NPTRs) were tested in a volcanic ash soil paddy field under dense (10×10 cm) and common (20×20 cm) planting densities. These lines were evaluated to have more spikelet numbers per panicle (SNP), lower filled grain rate (FGR), and lower rough grain weight per hill (RGWH). In dense planting, rough grain weight per stem (RGWS) was increased due to heavier culm and leaf dry weight (CLDW), and both RGWS and CLDW were related with the percentage of root distribution (%RWI) in the 10~30 cm soil layer, while in common planting, RGWS was not closely related with CLDW. SNP was highly related with root dry weight (RDW) in the 0~10 cm soil layer. FGR was mainly affected by RDW in the 10~30 cm soil layer under both planting densities. RGWS was positively correlated with top dry weight (TDW) and harvest index (HI), and TDW was positively correlated with RWI under common planting or %RWI under dense planting, and HI was positively correlated with RWI in the 10~30 cm soil layer only under dense planting. RGWS was closely related with root weight index by dry weight (RWI) in the 10~30 cm soil layer and %RWI in the 0~30 cm or 10~30 cm soil layer under dense planting, and with only RWI in the 10~30 cm soil layer under common planting. But RGWH showed the close positive relationship with RDW and RWI in the 10~30 cm soil layer under dense planting, while under common planting, it showed the close positive relationship with RWI and %RWI in the 10~30 cm soil layer or %RWI in the 0~30 cm soil layer. The deeper root system in rice, especially under dense planting, is important for high yield of NPTRs focusing on the increment of top mass production and harvest index.

Key words : rice, new plant type, yield, root distribution, soil depth.

The crop root system anchors the plant body and absorbs water and nutrients. Therefore, knowledge of the root system is essential not only for understanding growth and development of crops, but also for selecting useful management practices in agriculture.

Although study of the root is quite tedious and time-consuming, there has been several investigations on root system development of cereal crops under field conditions with reference to shoot growth (Biscoe et al., 1995; Foth, 1962; Gregory et al., 1978; Gaeriyama & Yamazaki, 1983; Mengel & Barber, 1974; Nakamoto, 1989; Tardieu et al., 1992).

But studies on root system development of rice plants grown in a paddy field under flooded conditions are limited (Beyrouty et al., 1988; Mawaki et al., 1990; Morita et al., 1988; Slaton et al., 1990).

Since Yoshida (1981) described the characteristics of the rice root system in terms of length, dry weight and volume, some studies have been conducted on the varietal variation of vertical or horizontal root distribution (Morita et al., 1995; Kang et al, 1994), individual variation at different growth stages (Cheema et al., 1979), the relationship between root and shoot characteristics (Morita et al., 1987) and between root system and lodging (Kim et al., 1996). However the information on the relationship between root characteristics and yield or its components is quite limited to inter-species of crops or under different cultural methods (Kawata & Yamazaki, 1978; Morita et al., 1986; Yamazaki & Harada, 1984).

The objective of this study is to examine the vertical distribution habit of rice roots and their relationship with yield and yield components in the flooded paddy field, by using the new type of IRRI's rice which are different from *japonica* or *indica* type of rice in tillering ability, spikelet number per panicle and filled grain rate (Peng et al., 1994).

MATERIALS AND METHODS

IR 72, an indica variety as a check and eight new types of IRRI's rice lines (NPTRs) were cultivated in volcanic ash soil in IRRI's paddy field during the dry season in 1996.

Pregerminated seeds of each line were sown on a nursery bed. The 4th or 5th leaf stage of seedlings were transplanted under two planting densities of 10 cm × 10 cm (dense) and 20 cm × 20 cm (common) with three replications under randomized complete block design. Each hill consisted of three individual plants.

Fertilizer was applied as a basal dressing before transplanting, first top dressing at the active tillering stage and the second at the panicle initiation stage, where the total applied nitrogen was 100 kg/ha.

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Soil sampling for root collection was taken just after harvesting of ripened rice plant. Two hills of each line were randomly collected for soil sampling with the sample size of 40 cm (length)×20 cm (width)×30 cm (depth) in common planting and 20 cm (length)×20 cm (width)×30 cm (depth) in dense planting, with three replications in each experiment plot.

To measure the vertical root distribution, soil samples were divided, at every 10 cm soil depth from soil surface, into three soil layers of 0~10 cm, 10~20 cm and 20~30 cm soil layer. The divided soil samples were carefully washed by water on a sieve and the root were collected.

Rough grain weight and its components were evaluated by using the same plant used as root samples. Dry weight of root (RDW), culm and leaf (CLDW), and panicle was measured after drying at 100℃ for 30 minutes and 80℃ for 2 days.

Root weight index (RWI) was calculated using the following formular, 5×(RDW in 0~10 cm)+15×(RDW in 10~20 cm)+25×(RDW in 20~30 cm soil layer). %RWI was the ratio of RDW at every soil layer to total RDW.

RESULTS AND DISCUSSION

Characteristics of yield and its components of the tested breeding lines

Yield and yield components of eight NPTRs under the two planting densities are represented in Table 1.

Spikelet number per panicle (SNP), filled grain rate (FGR), one thousand rough grain weight (1,000 RGW) and rough grain weight per hill (RGWH) were remarkably higher in common planting as compared to those in dense planting. SNP was higher in both planting densities, ranging from 104 to 193 grains in dense and 123 to 232 grains in common planting, compared with 78 and 101 grains of check variety, IR 72, respectively.

FGR of NPTRs was lower than that of IR 72 except for IR66160-5-2-3-2 in both planting densities. 1,000 RGW was 15 g to 23 g in dense and 16 g to 24 g in common planting, compared with 17 g and 22 g of their checks. RGWH was 4.4 g to 8.6 g in dense and 16 g to 30 g in common planting while IR 72 was 6.8 g and 30 g, respectively.

Therefore, NPTRs were generally characterized by more SNP, lower FGR and lower RGWH than IR 72. Only IR66160-5-2-3-2 showed higher FGR and RGHW in dense planting.

Correlation coefficients among the upper traits are shown in Table 2. SNP showed negative correlation with FGR, 1,000 RGW and RGWH, regardless of planting density, although their correlation coefficients were not significant. RGWH showed significant positive correlation with FGR in two planting densities and with 1,000 RGW only in common planting.

Root distribution in soil layer and root weight index

Table 1. Rough grain weight and its components in dense (10×10 cm) and common(20×20 cm) planting densities.

NPTRs	No. of grain per panicle		Filled grain rate (%)		1,000 grain weight (g)		Rough grain weight per hill (g)	
	Dense	Common	Dense	Common	Dense	Common	Dense	Common
IR65564-22-2-3	169	192	66.0	69.2	19.3	20.9	6.3	22.0
IR66160-5-2-3-2	146	151	76.1	82.7	22.7	23.5	8.6	30.1
IR66158-38-3-2-1	156	180	66.0	66.7	18.9	19.1	5.7	19.4
IR66159-189-5-5-3	24	141	63.1	62.6	15.6	17.5	4.4	15.9
IR66738-118-5-5-3	139	155	66.0	70.7	20.8	21.8	5.1	23.7
IR66160-121-4-4-2	104	123	70.0	70.6	21.4	22.3	6.9	24.1
IR65598-112-2	193	232	63.8	72.9	16.3	18.9	5.2	19.7
IR67299-44-3-2-2	190	209	63.4	66.2	14.6	15.5	6.6	19.9
IR 72	8	101	71.2	83.6	16.7	21.5	6.8	30.3

Table 2. Correlation coefficients among rough grain weight and its components across the eight IRRI NPTRs.

Items	Planting density	No. of grain per panicle(X1)	Filled grain rate(X2)	1,000 rough grain weight(X3)	Rough grain weigh per hill(X4)
X1	Dense†		−0.376	−0.699	−0.031
	Common‡		−0.231	−0.523	−0.242
X2	Dense			0.668	0.866**
	Common			0.748*	0.992**
X3	Dense				0.626
	Common				0.781*

† 10 × 10 cm planting density, ‡ 20 × 20 cm planting density.

Table 3. Vertical root distribution among groups classified by rough grain per hill under 10 × 10 cm and 20 × 20 cm planting densities.

Group	NPTRs	Rough grain weight per hill (g)	Root dry weight per stem (mg)					RWI†		%RWI†		CLDW† (g)	RGW† (g)	TDW† (g)	HI†
			0~10 cm	10~20 cm	20~30 cm	10~30 cm	0~30 cm	10~30 cm	0~30 cm	10~30 cm	0~30 cm				
10 × 10 cm planting density															
I	IR66159-189-5-5-3	4.4	111.1	7.0	2.0	9.0	120.1	0.16	0.71	118.7	581.2	3.2	1.3	4.5	0.38
	IR66738-118-5-5-3	5.1	64.7	7.3	2.2	9.5	74.2	0.16	0.48	221.7	657.7	4.6	2.3	6.9	0.34
	IR65598-112-2	5.2	160.7	6.0	1.9	7.9	168.6	0.14	0.94	81.6	558.1	3.8	2.2	6.0	0.36
	Mean	4.9c‡	112.2b	6.8c	1.9b	8.8c	121.0b	0.15b	0.71c	140.7c	599.0b	3.9b	1.9b	5.8b	0.33b
II	IR65564-22-2-3	6.3	155.5	12.7	3.3	16.1	171.6	0.27	0.61	158.7	612.9	3.5	1.7	5.2	0.32
	IR66158-38-3-2-1	5.7	159.3	11.7	3.4	15.1	174.4	0.26	1.06	148.0	604.5	3.7	1.7	5.4	0.31
	IR66160-121-4-4-2	6.9	74.8	12.5	4.4	16.9	95.7	0.30	0.67	310.9	701.1	3.7	1.8	5.5	0.33
	IR67299-44-3-2-2	6.6	122.2	12.9	4.3	14.2	139.4	0.22	0.91	179.9	654.2	3.7	2.0	5.7	0.35
	Mean	6.4b	122.2a	12.6b	3.9a	15.7b	141.9a	0.29a	0.81b	198.9b	656.5a	3.7b	1.8b	5.5b	0.33b
III	IR66160-5-2-3-2	8.6a	123.6a	15.0a	3.7a	18.7a	142.4a	0.32a	0.94a	223.6a	651.8a	4.4a	3.7a	8.1a	0.46a
20 × 20 cm planting density															
I	IR66159-189-5-5-3	15.9d	134.7c	6.8d	5.3b	11.1d	145.8c	0.23c	0.91c	160.6d	622.6c	3.9b	3.0b	6.9c	0.43b
II	IR66158-38-3-2-1	19.4	163.5	19.4	3.8	23.2	186.7	0.38	1.20	206.1	643.9	4.4	4.3	8.7	0.49
	IR65598-112-2	19.7	169.4	17.7	5.3	24.9	192.4	0.40	1.24	207.1	647.2	4.8	3.5	8.3	0.42
	IR67299-44-3-2-2	19.9	160.5	18.8	5.8	25.6	185.1	0.43	1.22	231.5	664.7	4.2	3.2	7.4	0.43
	Mean	19.7c	164.5a	18.6c	5.0b	24.6c	195.3b	0.40b	1.22b	219.8c	629.4c	4.5ab	3.8b	8.2bc	0.45b
III	IR65564-22-2-3	22.0bc	164.6a	28.6a	4.5b	43.1a	207.6a	0.54ab	1.36a	260.5b	657.7b	5.2a	4.2b	9.4b	0.44b
IV	IR66738-118-5-5-3	23.7	104.5	19.0	6.0	25.0	129.5	0.44	0.96	335.8	739.2	3.9	3.8	7.7	0.49
	IR66160-121-4-4-2	24.1	122.2	16.8	6.4	23.2	145.3	0.41	1.02	283.3	703.6	3.9	3.3	7.2	0.46
	Mean	23.9b	113.4d	17.9c	6.2ab	24.1c	135.4d	0.43b	0.99c	309.6a	721.4a	3.9b	3.5b	7.4c	0.47b
V	IR66160-5-2-3-2	30.2a	160.0b	25.3b	7.9a	33.2b	193.2b	0.58a	1.38a	298.9a	712.9a	5.0a	6.2a	11.2a	0.55a

† RWI : Root weight index estimated by dry weight of vertically distributed root in every 10 cm soil layer; %RWI : Root weight index estimated by % of dry weight of vertically distributed root in every 10 cm soil layer; CLDW : Culm and leaf dry weight per stem; RGW : Rough grain weight per stem; TDW : Top dry weight (CLDW+RGW)per stem; HI : Harvest index.

‡ Means followed by a common letter are not significantly different at the 5% level by RCBDMRT.

Table 3 shows vertical root distribution among groups classified on the basis of RGWH under dense and common plantings in the field. In dense planting, mean RDW, RWI and %RWI in the 10~20 or the 10~30 cm soil layer showed significant difference among the groups. Especially, the mean RDW in the 10~30 cm soil layer was shown to have significant difference with consistent deviation in the mean value among groups, showing an increasing trend along with the increase of RGWH, while the other root traits were not consistent. So, RDW in each layer, RWI and %RWI in the 10~30 cm soil layer were related with RGWH under dense planting.

CLDW, RGWS and HI were statistically significant between groups Ⅰ, Ⅱ and Ⅲ, showing that they increased as RGWH increased.

%RWI increased as RGWH increased, showing proficient differences among the five groups. But RDW in each soil layer and RWI showed little consistent trend even in the mean value among the five groups with high deviation from the mean value. These results indicated that RGWH had a close relation with the ratio of RDW in each soil layer to the total root weight instead of RDW distributed in each soil layer. It was shown that IR66738-118-1-2 and IR66160-121-4-4-2 (Group Ⅳ) owned higher %RWI in the 10~30 cm soil layer and finally, higher RGWH, despite that they had lower total RDW, while IR66158-38-3-2-1, IR65598-112-2 and IR67299-44-3-2-2 (Group Ⅱ) had lower %RWI and lower %RGWH in spite of the higher total RDW. IR66160-5-2-3-2 (Group Ⅴ) was found to have the highest total RDW, %RWI and RGWH among eight IRRI NPTRs.

Correlation among growth, yield and root distribution characteristics

Correlation coefficients among the traits of top dry weight (TDW) per stem and RDW per stem are shown in Table 4. CLDW, RGWS and TDW were positively correlated with %RWI in the 10~30 cm soil layer. Correlation coefficients among the three above-mentioned traits were positively significant under dense planting. These results suggest that RGWS increases as CLDW per stem increases, and CLDW and RGWS are mainly affected by the ratio of the root distribution (%RWI) in the 0~30 cm or the 10~30 cm soil layer under dense planting, where the vegetative growth of the rice plant was not enough to obtain the optimum yield of the individual plant, while CLDW per stem was significantly positively correlated with RDW in each layer of the 0~20 cm soil layer, total RDW and RWI in the 0~30 cm soil layer under common planting where the rice plant would vegetatively grow to some extent.

RGWS was significantly related with only RWI in the 10~30 cm soil layer under both planting densities and %RWI in the 0~30 cm or the 10~30 cm soil layer under dense planting, and TDW was positively related with RWI under common planting and with %RWI under dense planting. TDW was significantly correlated with CLDW per stem or RGWS, while correlation between CLDW per stem and RGWS was not significant under common transplanting. Therefore, RGWS was not affected directly by CLDW per stem, and it increased in proportion to an increase of RWI in the 10~30 cm soil layer under common planting.

Harvest index (HI) was closely related with RGWS but not with CLDW in both planting densities.

Table 5 shows the relationship between yield and root traits. Although correlation coefficients were not significant, SNP showed the positive correlation with RDW in the 0~10 cm soil layer and total RDW, while it showed the negative correlation with RDW in each layer of the 10~30 cm soil layer, RWI and %RWI under dense

Table 4. Correlation coefficients among the traits between top and root dry weight across the eight IRRI NPTRs.

Items	Planting density	Root dry weight per stem					RWI†		%RWI†		RGW†	TDW†	HI†
		0~10 cm	10~20 cm	20~30 cm	10~30 cm	0~30 cm	10~30 cm	0~30 cm	10~30 cm	0~30 cm			
Culm and leaf dry weight‡	10 × 10 cm	0.646	0.302	0.418	0.382	0.593	0.392	0.019	0.788*	0.778*	0.815*	0.943**	0.692
	20 × 20 cm	0.723*	0.714*	0.091	0.749*	0.846*	0.687	0.883*	0.055	0.120	0.581	0.769*	0.270
Rough grain weight‡	10 × 10 cm	0.350	0.549	0.486	0.662	0.261	0.701*	0.234	0.730*	0.733*	–	0.961**	0.973**
	20 × 20 cm	0.313	0.602	0.519	0.514	0.428	0.735*	0.630	0.411	0.382	–	0.959**	0.931**
Top dry weight‡	10 × 10 cm	0.506	0.460	0.479	0.541	0.392	0.581	0.124	0.794*	0.791*	–	–	0.888**
	20 × 20 cm	0.471	0.638	0.429	0.596	0.587	0.720*	0.739*	0.275	0.202	–	–	0.798*
Harvest index‡	10 × 10 cm	0.185	0.596	0.475	0.662	0.089	0.776*	0.318	0.669	0.683	–	–	–
	20 × 20 cm	0.065	0.471	0.488	0.342	0.165	0.583	0.390	0.500	0.521	–	–	–

† RWI : Root weight index estimated by dry weight of vertically distributed root in every 10 cm soil layer; %RWI : Root weight index estimated by % of dry weight of vertically distrbuted root in every 10 cm soil layer; RGW : Rough grain weight per stem; TDW : Top dry weight perstem; HI : Harvest index.

‡ The mean value per stem.

Table 5. Correlation coefficients between yield components and root related characters in the field across the eight IRRI NPTRs.

Items	Planting density	Root dry weight per stem					RWI†		%RWI†	
		0~10 cm	10~20 cm	20~30 cm	10~30 cm	0~30 cm	10~30 cm	0~30 cm	10~30 cm	0~30 cm
Grain number per panicle	10 × 10 cm	0.608	−0.108	−0.192	−0.265	0.568	−0.367	−0.400	−0.548	−0.484
	20 × 20 cm	0.705	0.283	0.397	0.238	0.666	−0.142	−0.551	−0.315	−0.413
Filled grain rate	10 × 10 cm	−0.198	0.644	0.454	0.727*	−0.116	0.768*	0.202	0.559	0.563
	20 × 20 cm	0.014	0.653	0.765*	0.572	0.197	0.836**	0.493	0.762*	0.748*
1,000 rough grain weight	10 × 10 cm	−0.089	0.426	0.416	0.596	0.011	0.699	0.128	0.431	0.357
	20 × 20 cm	−0.320	0.480	0.483	0.470	0.166	0.590	0.117	0.749*	0.709*
Rough grain weight per hill	10 × 10 cm	0.117	0.781*	0.758*	0.774*	0.240	0.845**	−0.417	0.588	0.611
	20 × 20 cm	−0.022	0.670	0.731*	0.581	0.170	0.804*	0.471	0.802*	0.785*

† RWI : Root weight index estimated by dry weight of vertically distributed root in every 10cm soil layer; %RWI : Root weight index estimated by % of dry weight of vertically distributed root in every 10cm soil layer.

planting. However under common planting, it showed non-significant positive correlation with RDW in every layer of the 0~30 cm soil layer, while it was non-significantly negatively correlated with RWI and %RWI. FGR was closely related with RDW and RWI in the 10~30 cm soil layer under dense planting, while under common planting, FGR was closely related with RDW in the 20~30 cm soil layer, RWI in the 10~30 cm soil layer and %RWI in the 0~30 cm or the 10~30 cm soil layer. 1,000 RGW showed significant positive correlation with both of the %RWI only under common planting. RGWH had significant positive correlation with RDW in each soil layer except for the 0~10 cm soil layer and RWI in the 10~30 cm soil layer under dense planting, while under common planting, it had significant correlation with RDW in the 20~30 cm soil layer, RWI in the 10~30 cm soil layer and both of the %RWI, agreeing to the report that the proportion of vertically growing root was important for the high yield of over five ton per ha (Morita et al, 1986, 1988). Therefore, SNP, FGR and RGWH were mainly affected by RDW distributed actually in the 10 to 30 cm soil layer under dense planting, and they were determined by the ratio of RDW distributed in the 20~30 cm soil layer under common planting (Mawaki et al., 1990).

RGWS was positively correlated with TDW and HI, and TDW was positively correlated with RWI under common planting or %RWI under dense planting, and HI was positively correlated with RWI in the 10~30 cm soil layer only in dense planting. The results imply that the deeper root system in rice, especially under dense planting, is important for high yield of NPTRs focusing on the increase of top mass production and HI.

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