Root Growth and Distribution in Some Japonica-Indica Hybrid and Japonica Type Rice Cultivars under Field Conditions*

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Abstract : The development of rice root system has been studied in Japonica-Indica hybrid cultivars (J-IH), Milyang 23 and Suweon 264, and Japonica type cultivars (JT), Nipponbare and Koshihikari, grown in a paddy field. Soil cores were taken below (and between) hill(s) at the panicle initiation, the heading and the grain-filling stages. After the soil cores were divided into layers by soil depth and the roots were washed out, length and weight of the roots in each soil layer were measured to calculate root length density (RLD) and root weight density (RWD). At the panicle initiation stage, there were no significant differences in RLD and RWD in the 0-25 cm soil layer below hill of each cultivar. Thereafter, RLD and RWD markedly increased, especially in J-IH, and at the grain-filling stage RLD and RWD of J-IH both below and between hills were significantly larger than those of JT. Such increases of RLD and RWD in J-IH after the panicle initiation stage occurred mainly in shallow soil layers. The soil depth of the maximum value in RLD and RWD below hill were different from each other; the 0-5 cm soil layer in RLD and the 5-10 cm soil layer in RWD. The specific root length in 5-10 cm soil layer below hill was smaller than those in the other soil layers below and between hills, especially in the later growth stage, which might depend on the distribution of root diameter and branching.

Key words : High-yielding rice cultivars, *Oryza sativa* L., Rice, Root length density, Root system, Root weight density, Specific root length.

水田で栽培した日印交雑稲品種および日本型稲品種の根量および分布：姜始龍・森田茂紀・山崎耕宇（東京大学農学部）

要 旨：東京大学農学部附属多摩農場の水田で栽培した日印交雑稲（密陽 23 号，水原 264 号）および日本型稲（日本晴，コシヒカリ）の根系の形成について検討した。幼穂分化期，出穂期および登熟期に，株下（登熟期は株下および隣接する 4 株の中央部である株条間の両者から）直径 15 cm の土壌モノリスを採取した。土壌表面から 0-5，5-10，10-15 および 15-25 cm の各土層別に，根を丁寧に洗いだし，根の長さとお重を測定した後，それぞれの土壌体積で割って根長密度（RLD）および根重密度（RWD）を算出した。幼穂分化期頃は株下 0-25 cm における RLD と RWD には品種間差は認められなかった。それ以降，いずれの品種においても RLD と RWD がともに増加したが，とくに日印交雑稲において増加が著しかった。登熟期には株下および株条間の両者において，日本型稲より日印交雑稲の根量が有意に多かったが，これはとくに株下第 1 層において顕著であった。各品種の RLD は株下第 1 層において，また RWD は第 2 層においてそれぞれ最高値をとった。そこで specific root length（単位根重当たりの根長）を算出したところ，株下第 2 層において最も小さい値を示したのに対し，株下の他の層や株条間では大きな値を示した。このことは，株下第 2 層中に株の基部が位置し，ここには相対的に直径が大きく分枝があまり発達していない冠根の基部が多く分布するのに対して，他の土層中には冠根の直径が細く，分枝が比較的発達した部分が多く分布するためと考えられた。

キーワード：イネ，根系，根重密度，根長密度，根量，多収性品種，日印交雑稲。

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The root system of a crop 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 for selecting useful management practices in agriculture. Although studying the root system is quite tedious and time-consuming, there has been several investigations on root system development of upland cereal crops under field condi-

tions with reference to shoot growth^{2,6,7,12,19,24,30,31,32}). On the other hand, studies on root system development of rice plants grown in a paddy field under flooded conditions are so limited^{1,18,21,28}) and have rarely been examined with reference to the growth stages^{1,28}).

The objective of this study is to survey the growth and distribution of a rice root system during the panicle initiation stage through the grain-filling stage and to discuss root system development with reference to shoot growth. In addition, the rooting pattern of Japonica-Indica hybrid rice cultivars (J-IH) was examined comparing with Japonica type rice cultivars (JT). J-IH is well-known as high-yielding cultivars bred and grown mainly in Korea in 1970s¹⁶). Therefore, many studies have already been done to examine the morphological and physiological characteristics of shoot development^{4,17,25,26,29}), while information on the root system is quite limited^{9,23}).

Materials and Methods

Four cultivars of paddy rice (*Oryza sativa* L.) were selected for this study; Milyang 23 and Suweon 264 of J-IH, and Nipponbare and Koshihikari of JT. These cultivars were grown in the paddy field of the Experimental Farm of the University of Tokyo in 1990. The soil type was a kind of volcanic ash clay. The pregerminated seeds of each cultivar were sown in a nursery bed on April 19 and the seedlings of the 6-leaf stage were transplanted in a paddy field on June 7. Planting density was 22.2 hills m^{-2} (row distance: 30 cm, hill distance: 15 cm) and each hill consists of one individual plant. Compound fertilizer (N : P : K at to 12 : 18 : 16%, respectively) was applied as a basal dressing before transplanting and there was no top dressing thereafter, where the total N, P and K were 50, 75, and 66.7 $kg\ ha^{-1}$, respectively. Other management practices were done according to the conventional method in the Kanto area.

The root system samples were taken at three growth stages, such as at around the panicle initiation stage (July 24), the heading stage (Aug. 17) and the grain-filling stage (Sept. 21). Three hills of each cultivar were randomly selected for sampling at each growth stage. The soil cores (15 cm in diameter and 25 cm in length) were taken below the hills with a cylindrical core sampler. At the grain-filling

Fig. 1. A schematic diagram showing positions of sample collection.

stage, additional sampling was done between the hills (Fig. 1). The excavated soil cores were divided into four layers by soil depth, such as 0–5, 5–10, 10–15 and 15–25 cm from soil surface. The roots in each soil layer were washed out very carefully with spraying water on a sieve (mesh size: 0.5 mm). After plant debris and soil particles were taken out, root length was measured with a Comair Root Length Scanner (Commonwealth Corp. Ltd., Australia)²⁰). Then, the roots were dried at 80° C for 24h to weigh.

Root length and root weight in each soil layer were divided by their soil volume to calculate root length density (RLD, $cm\ cm^{-3}$) and root weight density (RWD, $mg\ cm^{-3}$) as indicators of the dimension and distribution of a root system. Then the total root length was divided by the total root weight in each soil layer to calculate the specific root length (SRL, $cm\ mg^{-1}$) as an indicator of root morphology such as root diameter and branching degree⁵).

Results

1. Dimension of root systems

The heading dates in each cultivars were as follows, Aug. 10 for Koshihikari, Aug. 17 for Suweon 264, Aug. 21 for Nipponbare and Milyang 23. At the grain-filling stage, the

average number of the productive stems per one hill were greater in J-IH than in JT, that is, Suweon 264 (14.7 ± 1.7) > Milyang 23 (13.3 ± 3.3) > Nipponbare (12.7 ± 0.5) > Koshihikari (11.0 ± 0.8).

The average RLD in the top 25 cm of soil layer is presented in Fig. 2. At around the panicle initiation stage, the differences in RLD below the hill among the cultivars were small, and thereafter the average RLD increased with shoot growth more rapidly in J-IH than in JT. Finally, the average RLD of J-IH below the hill at the heading and the grain-filling stages was significantly larger than those of JT ($P \leq 0.05$). At the grain-filling stage, the average RLD of J-IH between hills was also larger than that of JT.

Average RWD in top 25 cm of soil layer below the hill substantially increased in J-IH after the panicle initiation stage, whereas the RWD of JT was almost constant or less. Then at the grain-filling stage, the average RWD in J-IH was significantly larger than in JT both below and between the hills ($P \leq 0.05$). The above mentioned results indicate that the root system development proceeds rapidly after the panicle initiation stage, especially in the J-IH compared with the JT.

2. Distribution of root systems

RLD and RWD in each soil layer below and between the hills were examined to compare root system distribution among the cultivars.

RLD below the hill of all the cultivars decreased with soil depth at any growth stage (Fig. 3). At the panicle initiation stage, there were no significant differences in the distribution pattern of RLD in soil layers among the cultivars, where the range of RLD were varied from about 4 to 15 cm cm^{-3} . After the panicle initiation stage, the RLD of J-IH substantially increased, especially in shallow soil layers (0–10 cm), and was larger than that of the JT in all the soil layers at the grain-filling stage, where the range of RLD was about 7 through 27 cm cm^{-3} . RLD of J-IH between the hills was significantly larger than that of JT in any soil layer ($P \leq 0.05$), where the RLD was about 7 through 19 cm cm^{-3} .

The maximum value of RWD below the hill, on the other hand, was not in the 0–5 cm soil layer, but in the 5–10 cm soil layer and then decreased with soil depth at any growth stage, which is a little different from the distribution

Fig. 2. Changes of average root length density (RLD) and root weight density (RWD) of four cultivars in 0–25 cm soil depth with reference to growth stage. I: LSD ($P < 0.05$).

pattern of RLD after the panicle initiation stage. After the panicle initiation stage, RWD of J-IH was markedly increased in 0–10 cm soil layer compared with that of JT. At the heading and the grain-filling stages, RLD of J-IH in the 0–15 cm soil layer was larger than that of JT, but there was no significant difference in 15–25 cm soil layer between them. At the grain-filling stage, RWD of J-IH in all the soil layer between the hills was also larger than that of JT.

3. An analysis with specific root length

As mentioned above, the distribution pattern of RLD and RWD in soil layers, in general, was similar among the cultivars at any growth stage. The detailed observation, however, showed that the soil layer with the highest value of RLD and RWD was somewhat different from each other below the hill, i.e., the 0–5 cm soil layer in RLD and the 5–10 cm soil

layer in RWD. Then the specific root length (SRL) defined as total root length divided by total root weight was calculated in each soil layer to characterize the root morphology (Fig. 4). At the heading and the grain-filling stages, SRL below the hill of all the cultivars decreased with soil depth down to 10 cm, and then increased down to 25 cm. Thus SRL at these two stages was at a minimum in the 5–10 cm soil layer. At the grain-filling stage, the difference in SRL of each soil layer between hills was relatively small, and SRL in any soil layer between the hills was similar to that in the shallow (0–5 cm) and deeper (15–25 cm) soil layers below the hill.

Discussion

The root system development of rice population grown in a paddy field has rarely been studied with reference to RLD or RWD. Moreover, most studies were conducted only at the grain-filling stage^{10,11,18,21)} and developmental studies are quite limited^{1,28)}. The development of the root system in different soil layers was examined in relation to shoot growth stage in this study. It was shown that the length and weight of the root system generally decreased with soil depth at any growth stage, and that RLD and RWD below

the hill considerably increased from the panicle initiation stage to the heading stage, especially in the shallow soil layer. These results suggest that the root system development might shift to a shallower soil layer with shoot

Fig. 3. Distribution pattern of root length density (RLD) and root weight density (RWD) in four cultivars with growth stage.

—: LSD ($P < 0.05$).

development. This speculation on the spatial distribution of the rice root system is supported by the studies on the growth direction of adventitious roots which determines the framework of the root system^{14,22)}. Because several studies have indicated that there is a possible relationship between root system distribution and grain yield in rice^{15,21)}, there is a need to study further the root system distribution and its contribution to yield.

Detailed analysis in this study, on the other hand, showed that soil layers with the maximum value of RLD and RWD below the hill are somewhat different from each other; 0–5 cm in RLD, and 5–10 cm in RWD. Cheema et al. (1979)³⁾ reported the similar distribution pattern of the RWD in the soil. We examined SRL which has been used an indicator of root morphology. It is usually thought that the root system with high value of SRL is composed of well-branched roots of small diameter⁵⁾. SRL of all the cultivars was at a minimum in 5–10 cm soil layer and larger in the 0–5 and 15–25 cm soil layers below the hill and this tendency became more clear at the heading and grain-filling stages. At the grain-filling stage, on the other hand, SRL in each soil layer was comparable between the hills. The basal part of the hills composed of stem is usually present in 5–10 cm soil layer and proximal parts of adventitious root emerged from stems are located in the same soil layer. Because the diameter of

adventitious root is relatively large at the basal part where branching is not so well-developed¹³⁾, SRL may be small in the 5–10 cm soil layer below the hill. The distal parts of adventitious roots, on the other hand, are mainly distributed in the peripheral part of the rootig zone. The diameter of adventitious roots, in general, decreases along the main axes, and branching has an intimate relationship to the changing pattern of the diameter along the parental roots²⁷⁾. Therefore, SRL in the deep soil below the hill and in each soil layer between the hills may be large. Thus, the result of an analysis on root system using SRL in this study suggests that SRL can be an effective indicator to examine the structure of the root system with reference to root diameter and branching.

Another objective of this study is to characterize the root system development of J-IH compared with JT. At the grain-filling stage, root length and root weight of J-IH were significantly larger than that of JT both below and between the hills (Fig. 2), which is consistent with the result reported by Murakami & Yoneyama (1988)²³⁾. In this study, root system development was examined with reference to growth stages of shoot. There were no significant differences in length and weight of the root system between J-IH and JT at the panicle initiation stage. Development of root system, thereafter, proceeded with growth

Fig. 4. Distribution pattern of specific root length (SRL) with growth stage.

stage, especially in J-IH. The length and weight of root system are thought to be determined by both number and size of adventitious roots. It is already known that the number of adventitious roots depends on the tiller number in rice⁸⁾. Although the data of the root number per stem is not available in this study, the average length of an adventitious root with all their lateral roots per stem is larger in J-IH. It was previously reported, on the other hand, that J-IH form well-branched adventitious roots compared with JT after panicle initiation stage⁹⁾. Therefore, the increase in length of root system in J-IH after the panicle initiation stage may be due to development of adventitious roots with higher branching degree as well as to the increase in the number of adventitious roots. Detailed analyses on root system from the viewpoint of number and size of shoot unit bearing roots are in progress.

J-IH is a high-yielding cultivar and generally shows the following characteristics after panicle initiation or heading stages i.e. high photosynthetic ability of individual leaf⁴⁾, high translocation rate of carbohydrate from leaf and stem into panicle^{26,29)}, superior canopy structure²⁵⁾, rapid leaf senescence and tiller dying¹⁷⁾ and so on. The information on root system, on the other hand, has been quite limited. Results obtained in this study suggest that a well-developed root system of J-IH at the later growth stage might have a possible relationship to the above-mentioned shoot characteristics and high yield, though the physiological mechanism is still unknown. The understanding of root system development with reference to shoot structure which will be determined by both number and size of shoot units, in addition to data of dry matter production and the partitioning, will help us to consider the contribution of root system to shoot growth and yield in J-IH.

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