

Comparative Analysis of Root and Shoot Growth between Tongil and Japonica Type Rice

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ABSTRACT

Root and shoot development of two rice (*Oryza sativa* L.) cultivars with different genetic backgrounds was studied with reference to their relative growth. Tongil type (indica-japonica hybrid) cultivar 'Kuemkangbyeon' and japonica cultivar 'Koshihikari' were grown in 5000⁻¹a Wagner pots under flooded condition. Three plants with roots of both cultivars were taken in every phyllochron through the heading stage to record morphological characteristics of shoot and root system. Compared to Koshihikari, Kuemkangbyeon produced more tillers and had greater shoot weight and leaf area per hill. Length and weight of the root system in both cultivars increased exponentially with time. At the same time, root system development was significantly faster in Kuemkangbyeon than in Koshihikari after the panicle initiation stage. As a result, Kuemkangbyeon has a vigorous root system which consists of larger number of nodal roots compared to Koshihikari. Also, the root length and weight per unit leaf area of Kuemkangbyeon were larger than those of Koshihikari in the later half of growing period, which suggests possible higher physiological activity of the root system of Kuemkangbyeon which is known as a high-yielding cultivar. The relationship between root traits (crown root number, total root length, and root dry weight) and shoot traits (leaf area and leaf+culm dry weight) in both cultivars closely showed allometry until the flag leaf stage.

Key words: allometry, high-yielding cultivar, *Oryza sativa* L., rice, root, shoot-root ratio.

Most crop scientists have been focusing mainly on the structure and function of shoots, because they are directly or indirectly related to crop yield. A root system, however, is an important part of crop, because it provides anchorage for the plant body and absorbs water as well as nutrients required for growth and development of a whole plant. In fact, most important agricultural practices, e.g. tillage, fertilization, and water management, affect a root system through soil. Therefore, information about a root system development is essential for selecting suitable management practices in crop production.

Because rice is one of the most important crops, especially in Asia, considerable amounts of studies have been done including root system development. As a result, fundamental principles of root system development in rice are already understood (for example, Fujii, 1961; Kawata et al., 1963). Many investigations have been reported

in development of root system under various environmental and cultural conditions (Beyrouy et al., 1988; Mawaki et al., 1990; Kang et al., 1994; Tanaka & Arima, 1996). However, comparisons among cultivars with different genetic backgrounds (Kang et al., 1994; Morita et al., 1995) as well as examination of shoot-root relationships (Mori, 1960; Suga & Yamazaki, 1988; Shin & Lee, 1996) have hardly been reported. The information of shoot-root relationships with reference to different genetic backgrounds are quite important for improvement of rice cultivation and for breeding high-yielding cultivars.

The objective of this study was to examine growth dynamics with special reference to root system development as well as the shoot-root relationship in rice cultivars with different genetic backgrounds. Another objective of this study was to characterize root system development with reference to shoot-root relationships in Tongil type cultivar, because information on their root system development which might partly be related to high-yielding capacity has not yet been fully elucidated.

MATERIALS AND METHODS

Plant materials

Two cultivars of rice (*Oryza sativa* L.), Kuemkangbyeon (Suwon 258) of a Tongil type (indica-japonica hybrid) and Koshihikari (japonica type), were used for the experiment, because they are representative rice cultivars of Tongil type and japonica type in Korea and Japan respectively, and because they have quite different genetic backgrounds. Pregerminated seeds of both cultivars were seeded on May 19, 1992 in 5000⁻¹a Wagner pots which were filled with volcanic ash clay soil from the Experimental Farm of The University of Tokyo after fertilized with 2.0 g of NH₄SO₄, 2.4 g of P₂O₅ and 0.7 g of KCl. All the pots were placed outdoors spaced at 35 cm. After thinning into one plant per each pot at 5th-leaf stage, plants were grown under flooded condition.

Each three plants from both plots were taken at every leaf emergence from the 6th-leaf stage through the heading stage. Those plant materials were separated into shoots and roots, and root samples were immediately washed by spraying water on a sieve (mesh size: 0.5cm) then stored in a refrigerator at 4°C for the following measure-

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ments.

Measurements of shoot and root traits

After culm number per plant and leaf number on a culm were recorded, surface area of still green leaves of a whole plant was measured with a machine (AAM-4, Hayashi Denko Ltd., Japan). After the above-mentioned measurements, all the shoot were dried at 80°C for 48 hours to weigh the dry weight.

Within 5 days after sampling, the number and length of nodal root axes longer than 5 cm were recorded. After all or subsampled nodal roots were cut into 2~3 cm segments, total root length including all the lateral roots was measured with a Comair Root Length Scanner (Commonwealth Corp Ltd., Australia) to measure or estimate total root length per plant. Then the total root length was divided by the total length of their root axes to calculate the branching index as an indicator of the branching degree. After the above-mentioned measurements, all the roots were dried at 80°C for 48 hours then weighed.

Analysis of shoot-root relationships

Shoot-root relationships were examined by examining root length/leaf area ratio, root dry weight/leaf area ratio, and shoot dry weight/root dry weight ratio. In addition, allometry was used for analysis of such shoot-root relationships, because there usually is an allometric relationship between two parts (X and Y) of plant body as follows,

$$Y = bX^k.$$

The allometry formula can be converted into natural logarithm,

$$\log_{10}Y = K \cdot \log_{10}X + \log_{10}b$$

where Y and X are shoot and root traits respectively, K is the relative growth coefficient which is a significant index to characterize development patterns, and b is a constant (Hunt, 1990 ; Suga & Yamazaki, 1988).

RESULTS AND DISCUSSION

Shoot growth

New leaves emerged successively on main culms of both cultivars in quite similar pattern during whole growing period, while leaf unfoldings after the 8th-leaf stage were slower in both cultivars (Fig. 1-A). The heading date of Kuemkangbyeoo was 7 days earlier than that of Koshihikari. The total number of leaves on a main culm, on average, was 14.0 in Kuemkangbyeoo and 14.8 in Koshihikari. Leaf senescence, however, proceeded somewhat more rapidly in Kuemkangbyeoo than in Koshihikari during later growing stages (Fig. 1-B).

Culm number per plant in both cultivars increased and

reached their maximum around 50 days after seeding (DAS), and then decreased (Fig. 1-C). Culm number of Kuemkangbyeoo was larger than that of Koshihikari at their maximum tillering stage, though culm number decreased more rapidly in Kuemkangbyeoo than in Koshihikari thereafter. The number of green leaves per plant changed as those of tillers died (Fig. 1-D). The area of green leaves reached their maximum at the flag leaf emergence stage (70 DAS) in Kuemkangbyeoo and at the heading stage (85 DAS) in Koshihikari, respectively and decreased more rapidly in Kuemkangbyeoo (Fig. 1-E). Such decrease in leaf area was due to the death of green leaves mainly on non-bearing tillers. These facts indicate that life course of tillers with leaves proceeded more rapidly in Kuemkangbyeoo than in Koshihikari.

There was no significant differences in shoot dry weight between two cultivars during early growth stages, while shoot dry matter production in Kuemkangbyeoo was larger than in Koshihikari after the panicle initiation stage (50 DAS) through the heading stage (Fig. 1-F).

These results suggest that shoot growth was more vigorous in Kuemkangbyeoo than in Koshihikari, because of high tillering capacity. At the same time senescence of shoots proceeded more rapidly in Kuemkangbyeoo than in Koshihikari.

Root growth

The number of nodal roots in both cultivars increased exponentially with each growth stage to reach the maximum at the later growth stages. Kuemkangbyeoo had more nodal roots than Koshihikari after the 10th leaf stage (Fig. 2-A). This was probably caused by the increase in the culm number which was almost the same in both cultivars (Fig. 1-C). These results agree with those of other studies where Kuemkangbyeoo produced larger number of nodal roots per phytomer (Harada et al., 1994 ; Kang et al., 1996b). The results of this study indicate that Kuemkangbyeoo had a larger root mass by producing a larger number of nodal roots than that of Koshihikari.

Mean length of the nodal root axis, in contrast to the number, increased gradually with time in both cultivars, and was somewhat longer in Koshihikari than in Kuemkangbyeoo throughout most of the growing period (Fig. 2-B). The total length of the nodal root axes per plant increased in quite similar pattern to their number (Fig. 2-C), which suggests the total length of nodal root axes is mainly depending on their number rather than their mean length. Both total length and total dry weight of all the roots including any lateral roots increased with a typical sigmoid curve (Fig. 2-D, E) where root system development was more vigorous in Kuemkangbyeoo than in Koshihikari after the 11th-leaf stage (40 DAS). The branching index declined slightly in the former half of the growing period and then increased after 10th-leaf stage to reach the maximum at the later growth stages (Fig. 2-F). The changing pattern of the branching index is almost

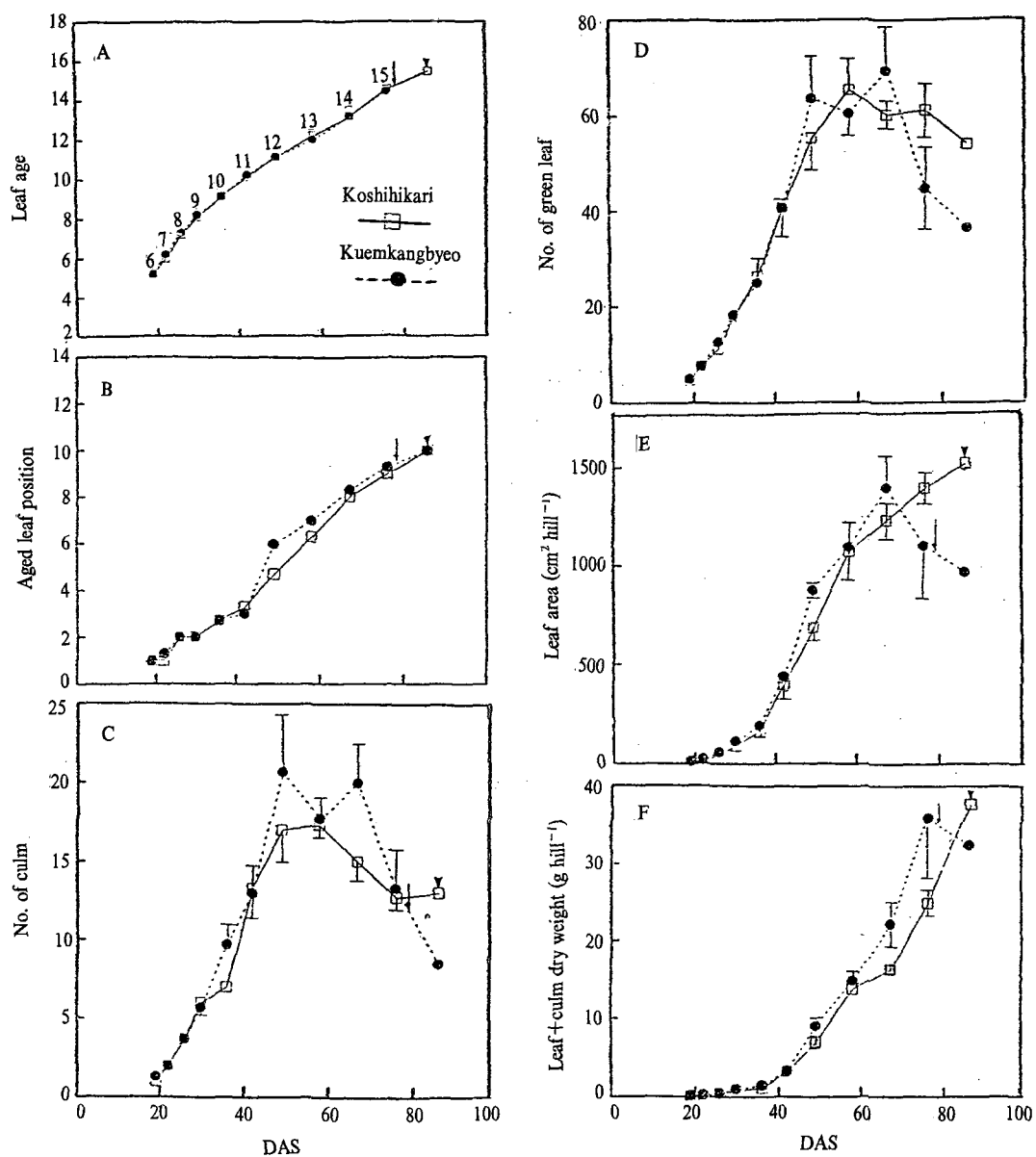


Fig. 1. Time course changes of shoot traits along the DAS (days after seeding) in two cultivars, Kuemkangbyeo (Suwon 258) and Koshihikari; leaf age (A), aging leaf position (B), number of tillers (C), number of green leaf (D) and leaf area per hill (E) and leaf+culm dry weight (F).

↓, ▼: heading date for Kuemkangbyeo, Koshihikari, respectively.

All and half size longitudinal bars of each plots shows all and half values of each standard deviation, respectively.

the same in both cultivars, while its value was slightly higher in Koshihikari than in Kuemkangbyeo at the later growth stages (Fig. 2-F). Such difference in the branching pattern between two cultivars is not coincident with our former observation (Kang et al., 1996a) and other report (Chae & Lee, 1980). Although the reason is unknown at present, total root length must be somewhat underestimated, because of the machine performance (Kang et

al., 1993). Nevertheless root system development seemed to be more vigorous in Kuemkangbyeo than Koshihikari, mainly because Kuemkangbyeo produced more nodal roots than Koshihikari did, which is coincident with the results of our former study (Kang et al., 1996b).

The above-mentioned results as well as most previous studies (Beyrouy et al., 1988 ; Kang et al., 1994) suggest that root system development in rice could proceed even

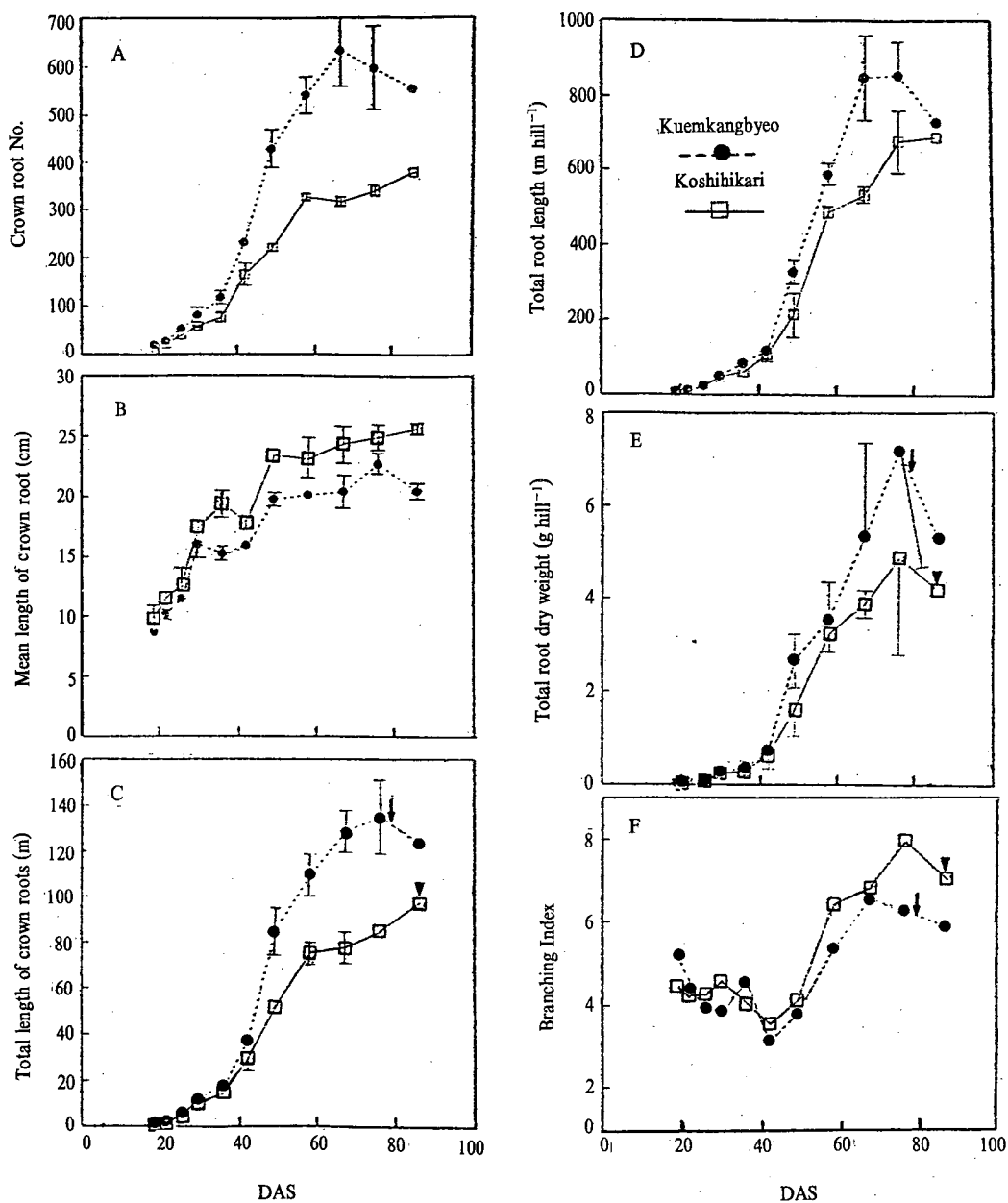


Fig. 2. Time course changes of root traits along DAS in rice cultivars Kuemkangbyeo and Koshihikari; number of crown roots per hill (A), mean length of a crown root (B), total length of crown roots (C), total root length per hill (D), total roots dry weight per hill (E) and branching index (F).

after the tillering or panicle formation stage. For example, we previously reported that Tongil type rice cultivars showed vigorous root system development between the panicle initiation and heading stage compared to japonica cultivars and that such root system development mainly resulted from formation and growth of both nodal and lateral roots (Harada et al., 1994; Kang et al., 1994)

Suga & Yamazaki (1988) also examined the root system development with reference to the phyllochron using

a japonica rice cultivar and reported quite similar results to ours. However, they also reported that mean length of nodal axes as well as the branching index increased linearly with phyllochron, which is almost the same as our results in this study, though the reason is unknown at present.

Shoot-root relationships

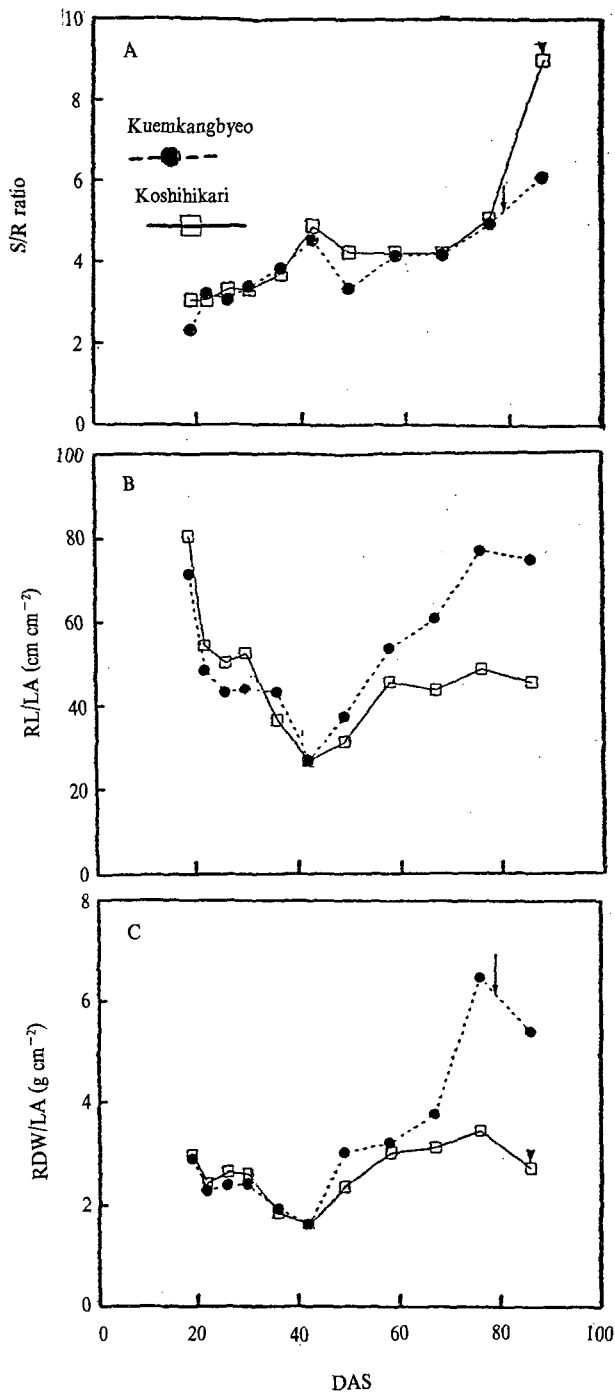


Fig. 3. Time course changes of shoot-root ratio (A), root length to leaf area (B) and root dry weight to leaf area (C) along DAS in rice cultivar Kuemkangbyeo and Koshihikari.

Shoot to root ratio in dry weight increased gradually from two to eight throughout the growing stage (Fig. 3-A). The ratios of root length and root dry weight to

leaf area in both cultivar decreased and then increased before and after the 11th-leaf stage (40 DAS) respectively, which was similar to the branching index (Fig. 3-B,C). In the latter half of the growing period, those ratios were significantly higher in Kuemkangbyeo than in Koshihikari. Results obtained in this study indicate that root systems especially in Kuemkangbyeo continued to develop after the panicle initiation stage which is coincident with our former results (Kang et al., 1994), possibly because an individual leaf of Tongil type cultivars has high photosynthetic ability (Cho & Murata, 1980 ; Heu et al., 1994).

Because root growth should proceed in harmony with shoot development, shoot-root relationships were examined with reference to allometry as follows,

$$\log_{10}(\text{shoot traits}) = K \cdot \log_{10}(\text{root traits}) + \log_{10}b$$

where K, the allometry coefficient, is an index to characterize the developmental pattern. When K was smaller than 1, it means root growth advantages for shoot growth and vice versa. Although there were quite similar relationships between the total number of nodal roots and shoot growth (leaf area and shoot dry weight), the slopes of the coefficient lines in both cases were larger in Koshihikari than in Kuemkangbyeo (Fig. 4-A, B). These facts suggest that root growth was more vigorous in Kuemkangbyeo than in Koshihikari, which might be a possible reason why Tongil type cultivars have higher yielding potential (Cho & Murata, 1980 ; Kubota et al., 1989).

The allometry curve in both cultivars between the root traits (total root length and total root weight) and shoot traits (total leaf area and total shoot dry weight) were quite similar throughout whole growing period (Fig. 4C~F). However, the allometric curves between the total root mass and total leaf area were different from each other in the former and latter halves of the growing period in both cultivars. K of the formula in both cultivars is lower in the latter half of the growing period, which indicates root growth has an advantage for leaf area development. Mori (1960) reported that there existed allometry between shoot and root weight throughout the growing period until the heading stage regardless of cultivars and culture conditions. Suga & Yamazaki (1988) also found an allometry between the total root length and total leaf area where the relative growth coefficient changed with leaf emergence. These results indicate that root growth could be more vigorous than shoot development during the late growth stage.

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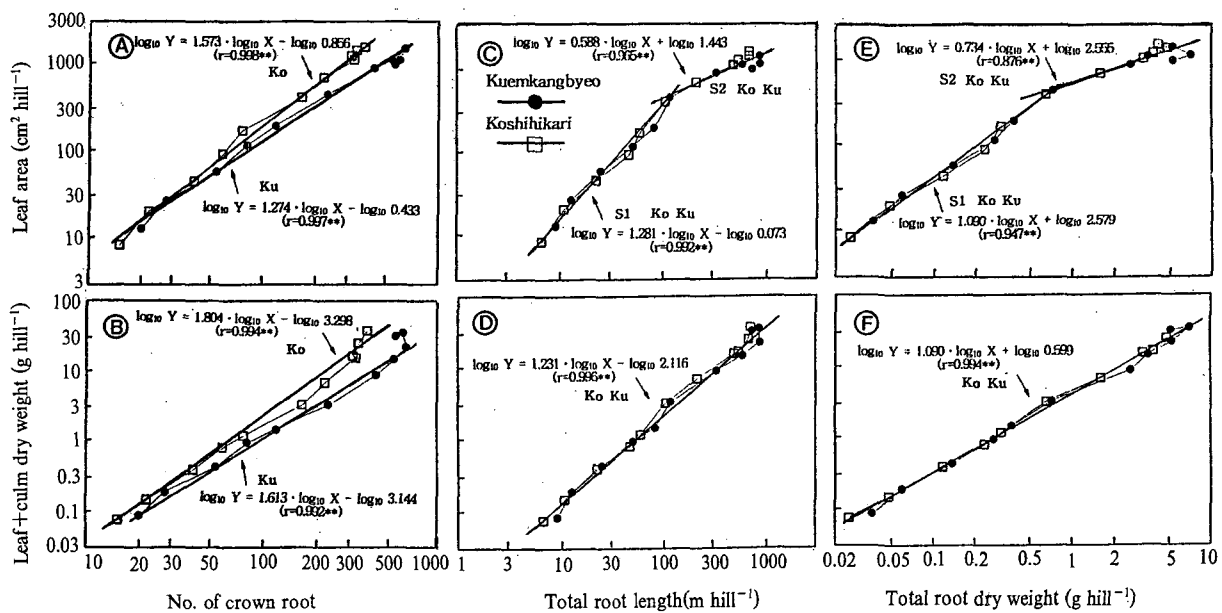


Fig. 4. The allometry relationships between root and shoot traits of two rice cultivars Kuemkangbyeo (Ku) and Koshihikari (Ko): leaf area–number of crown roots (A), leaf+culm dry weight–number of crown roots (B), leaf area–total root length (C), leaf+culm dry weight–total root length (D), leaf area–total root dry weight (E) and leaf+culm dry weight–total root dry weight (F).
S1: stage one, S2: stage two.

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