# The Root System Formation and Its Possible Bearings on Grain Yield in Rice Plants

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Recent remarkable increase in rice yield in Japan is dependent on various technological innovations such as improvements in cultural techniques, including manuring, control of diseases, insects or weeds, and the development of excellent varieties. As one of the bases for these improvements, a great number of scientific researches on rice plants have been done. But, most of them are concerned with aerial parts of plant, i.e. the leaf, the stem and the ear.

However, the root system, complicatedly spreading in soil, is none the less important. In an attempt to present the morphological implications of the root system of rice plants, recent studies on the process of crown root formation, the morphology of crown roots and the pattern of their distribution in soils are summarized in this paper. In addition, their possible bearings on grain yield is also discussed.

Research results presented in this paper have been obtained in a series of investigations carried out in our laboratory with the leader Dr. S. Kawata.

## Formation of crown root primordia

The crown root primordia in rice plants originate from the innermost cells of ground meristem adjacent to the peripheral cylinder of vascular bundles and fibers in stem[4]. First of all, primordia begin with undifferentiated initial cells dividing randomly, and in these cells, thereafter, the epidermis, the cortex and the stele are differentiated. Subsequently, in the stele the vascular tissues are initiated, and thus the primordia are completed as organized bodies. As these conductive cells mature and commence their function, the primordia begin to emerge and elongate to become crown roots.

Since the crown root primordia in rice plants arise endogenously and the course of their growth is closely correlated to that of the shoots on which they are formed, descriptions based on the concept of 'shoot unit' were

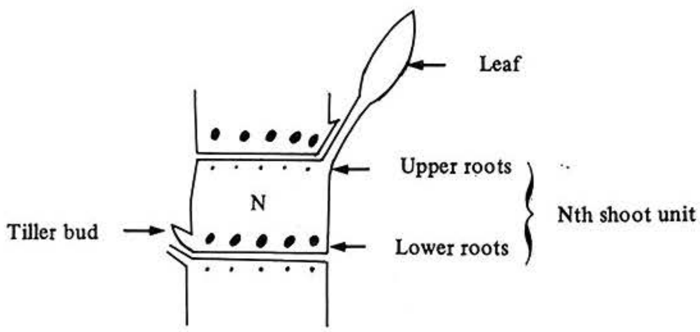


Fig. 1. Schematic expression of a shoot unit

employed throughout the investigations. The concept provides that a shoot of rice plants is considered to consist of a series of shoot units, each comprising a stem segment with an apical leaf, a basal tiller bud and upper and lower roots (Fig. 1)[1]. According to the concept, the growth of a shoot, on which leaf primordia are initiated successively, is thought to be the process that successively younger shoot units are added terminally.

Based on such a view point, the development of crown roots was found to proceed in the following manner.[2]. They initiate primarily in the shoot unit with the leaf just emerging. When this shoot unit is designated arbitrary as the N-th shoot unit counted from the base, crown root primordia completed as organized bodies are present in the lower (N-2)-th shoot unit, and the emergenc of crown roots is observed at the (N-3)-th shoot unit. Consequently, leaf emergence is usually synchronized with the emergence of roots three shoot units below.

## Growth and morphology of crown roots

Growth of crown roots proceeds further with the following regularity[1]. Crown roots (primary roots) on (N-4)-th shoot unit begin to produce secondary roots, and on the crown roots of (N-5)-th shoot unit the secondary roots begin to produce tertiary roots. Accordingly, roots formed on a shoot unit produce successive order of branches in every plastochron (Plate 1).

In a mature root system, each crown root exhibits morphologically diverse form[1]. The form varies with the rooting position on a shoot unit, being usually larger in diameter and longer in final length in lower roots than upper ones of the same shoot unit. The form of crown roots is also modified by growth duration of the roots. Thus, 'stunted roots' (less than 5 cm in length), 'lion-tail-like roots' with many strong branches at the tips, and normally elongated roots (more than 5 cm in length) are distinguished in a mature root system (Plate 2). The normally elongated roots are further classified into three types on the basis of different rates of acropetal decrease in their diameters[11]. Namely, the crown roots showing low, intermediate and high deceasing rates are designated A-, B- and C-type roots, respectively, and in this order the roots become shorter in final length (Plate 3). Moreover, these three types of roots usually show different branching habit: the highest branching density for C-type roots.

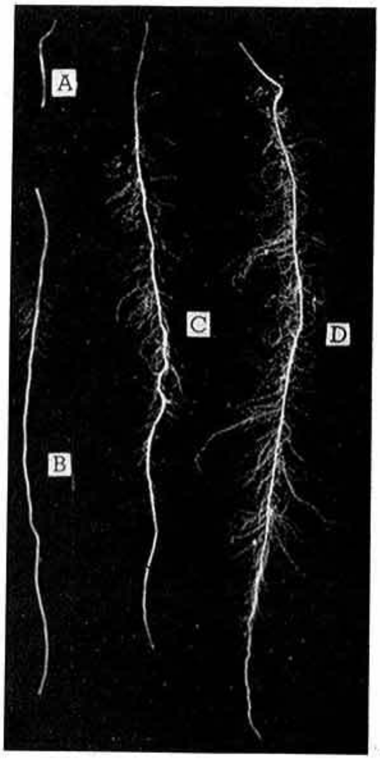


Plate 1. Growth of a lower root produced on the 4th shoot unit

A: at the time when the leaf begins to emerge on the 7th shoot unit (emergence of 7th leaf),
B: at the time of emergence of 8th leaf,
C: at the time of emergence of 9th leaf,
D: at the time of emergence of 10th leaf.

The composition of these many types of roots differs with successive shoot units pro-

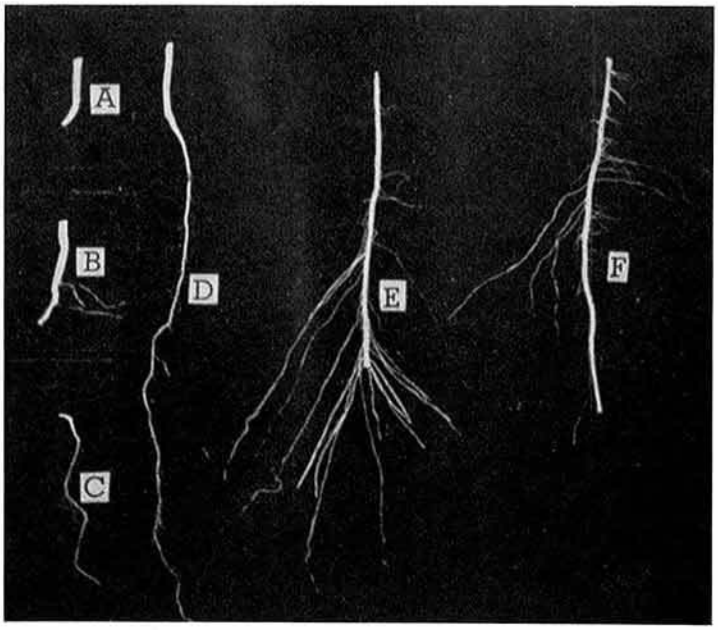


Plate 2. Various types of stunted roots taken from farmer's paddy fields
E: lion-tail-like root

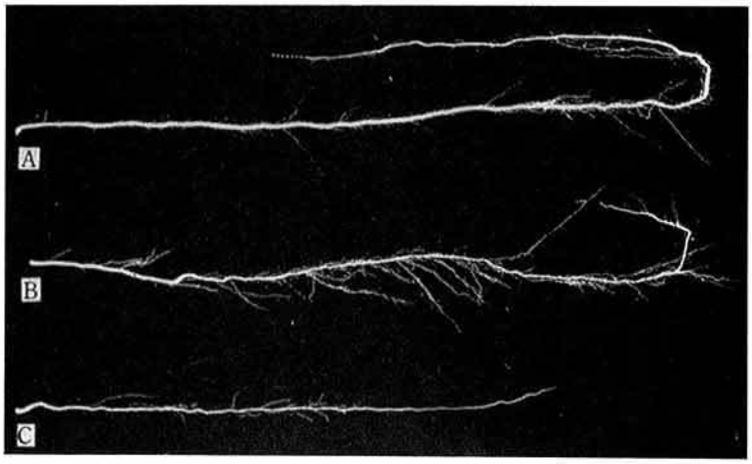


Plate 3. Three types of elongated roots
The long roots are bent for photographing

duced according to the developmental stages of the plants. The number of emerged roots (stunted roots + elongated roots) per each shoot unit increases gradually from the fifth to the ninth shoot unit, reaching the maximum at the ninth shoot unit (Fig. 2)[8]. Thereafter, it decreases steeply in the tenth and the upper shoot units. Although the number of stunted roots and that of elongated roots show similar changes as observed in the number of roots emerged, that of stunted roots tends to exceed that of elongated ones in the upper shoot units. Therefore, the majority of roots formed on middle shoot units are elongated

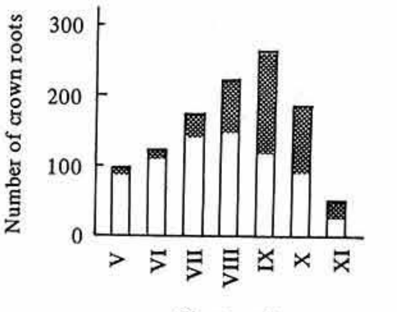


Fig. 2. Composition of crown roots formed on successive shoot units of a hill

Empty column: crown roots more than 5 cm in length
Black column: stunted roots

ones, while the majority of roots formed on upper shoot units are stunted roots.

Throughout the plant development, the composition of types of elongated roots also changes[11]. That is, the majority of elongated roots in the fifth to the ninth shoot units belong to A-type (Fig. 3), whereas most of the

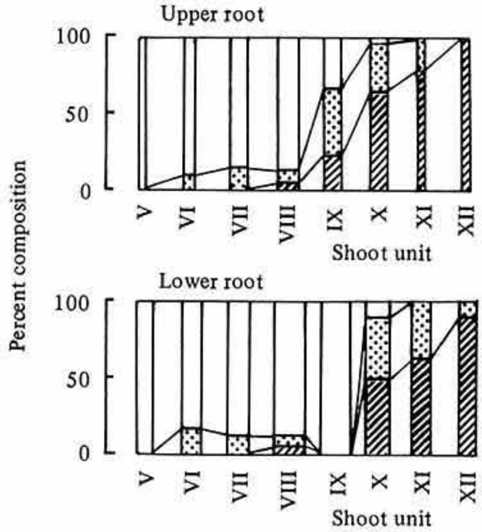


Fig. 3. Percent composition of different types of elongated roots to the total number of crown roots

Empty column: A type
Dotted column: B type
Hatched column: C type

elongated roots in the tenth and the upper shoot units belong to C- or B-type.

On the whole, the majority of roots formed during middle stage of plant growth are thick and long, while most of roots formed during later stage are stunted roots or thin and short ones. It is of interest that the stage, at which roots on the ninth shoot unit are formed, coincides just with the stage of transition from the vegetative to the reproductive phase.

## Root systems in soil

At the maturing stage of plants, the root system exhibits roughly an elliptical shape stretched somewhat horizontally in the longitudinal plane (Plate 4)[1]. The root system consists of a great number of crown roots extending radially from the base of the plant. The growing direction of each crown root seems to be determined by its position of emergence on a stem. Results obtained with main stems (Table 1)[1] show that the upper roots formed on each shoot unit tend to grow horizontally, irrespective of the position of the shoot unit on a stem. The lower roots formed on each shoot unit, on the contrary, grow in various directions according to the position of the shoot unit on a stem, i.e. the lower roots on the basal shoot units grow horizontally, those on the successively higher shoot units tend to grow obliquely or vertically, and those on the highest root-bearing shoot units again grow in horizontal direction. Such growth habits of crown roots as exemplified by main stems are also observed in tillers as well.

As mentioned earlier, the crown roots of rice plants emerge and grow in successive order from the basal shoot unit upward, in accordance with the growth stages of the plants. Therefore, from the foregoing findings, the process of root system formation is recognized as follows. The crown roots emerged at the earlier growth stage of plants occupy shallow top-soil. Among the crown roots developed later, some ones remain in top-soil, but many others, most of which belong

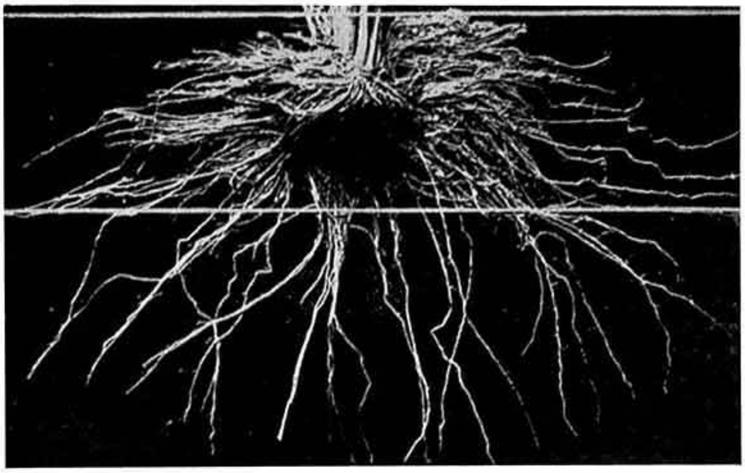

Plate 4. A profile of a mature root system in a longitudinal plane of soil
Upper line: soil surface
Lower line: plow sole

**Table 1. Distribution in soil of elongated crown roots formed on successive shoot units**

| Root | Soil layer | Percent dstribution of roots to different soil layers | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Roots emerged from each shoot unit indicated below: | | | | | | | | |
| | | III | IV | V | VI | VII | VIII | IX | X | XI |
| Upper root | Subsurface | 53% | 50 | 46 | 44 | 42 | 70 | 45 | 75 | 0 |
| | Intermediate | 47 | 32 | 42 | 44 | 34 | 30 | 39 | 20 | 100 |
| | Obliquely lower | 0 | 15 | 8 | 12 | 11 | 0 | 3 | 0 | 0 |
| | Vertically lower | 0 | 3 | 4 | 0 | 13 | 0 | 13 | 5 | 0 |
| Lower root | Subsurface | 67 | 45 | 3 | 12 | 9 | 11 | 4 | 42 | 100 |
| | Intermediate | 33 | 49 | 44 | 46 | 44 | 46 | 20 | 50 | 0 |
| | Obliquely lower | 0 | 3 | 44 | 21 | 32 | 25 | 36 | 4 | 0 |
| | Vertically lower | 0 | 3 | 9 | 21 | 15 | 18 | 40 | 4 | 0 |

to A-type, penetrate the plow-layer and extend deeply into the sub-soil. The latter comprises a deeper part of root system. Thus, the maximum dimension of root system is attained at the stage just prior to the panicle formation. After this stage, newly emerging roots spread usually in the soil layer 5 cm in depth from the surface and form specific matted structures called the 'superficial roots' (Plate 5)[5]. These latest formed crown roots belong B- or C-type and are characterized by their high branching habit. Sometimes the branching reaches the 6th order, and branched laterals continue to grow until the full-ripe stage of plants[3].

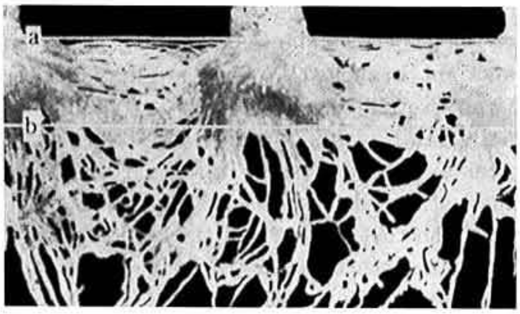


Plate 5. Mat-like superficial roots formed in a mature root system
Line a: soil surface
Line b: 5 cm depth from soil surface

To increase rice yields, many agricultural techniques have hitherto been employed in Japan. Among them, the application of nitrogenous fertilizer exerts conspicuous effects on root system formation. For example, high nitrogen supply suppresses the crown root elongation, resulting in the delimitation of root system to a great extent. Even with a given quantity of nitrogen, the split application as top-dressing is more effective on the formation of superficial roots than a single application as basal dressing[5]. Although the underlying mechanisms are not known, application of organic manure also promotes the formation of superficial roots.

Water management of paddy fields also affects the root system formation. The number of crown roots, that penetrate into the soil below 20 to 30 cm in depth, decreases on one hand, and the number of crown roots, that comprise the superficial roots increases on the other hand, in the paddy fields irrigated intermittently or drained in midseason, as compared with the fields under continuously flooded condition. Moderate water percolation in soil, at the rate of about 3 cm decrease in water depth per day, increases the number of deeply penetrated crown roots[7].

## Root system and grain production

From one hill of rice plants in farmer's fields, as many as 1000 to 2000 crown roots are produced; among them 400 to 1000 roots elongate more than 5 cm in final length and others are stunted[8]. Throughout the whole growth period of plants, the crown roots with abundant branched laterals might contribute to the growth and development of plants and finally grain yields, by their activity to absorb water and mineral salts in soil. Although the cause still remains obscure, correlations between the root system and the crop production have been ascertained by several field surveys.

In various fields where usual rice production is practiced, a close correlation was found between weight of superficial roots in unit soil volume and yields of brown rice (Fig. 4). However, the linear regression seems to exist only within a range of yield up to about 6000 kg of brown rice per ha. On the other hand, any distinct relationship was not noticed in the fields showing higher yields beyond that range[9].

As already mentioned, the superficial root formation is promoted by increased number of times and quantity of nitrogen application. A comparable effect of nitrogen in promoting stunted root formation was also demonstrated, as the number of stunted roots increases with the increase in the total number of emerged roots[10]. Meanwhile the number of ears per hill is also shown to be closely correlated with that of elongated crown roots per hill. This fact suggests that the increased number of elongated crown roots has some significances on the yield increase occured so far in Japan[12].

It is widely accepted that the recent development of cultural technique for high yields in Japan has been realized by means of increased rates of nitrogen application combined with varieties with many tillers and short straw. Such technique is considered to be effective in increasing the number of elongated crown roots and ears per unit field area, with concomitant increment of stunted roots and superficial roots as well. However, the above fact that yield increase beyond a certain yield level can not be expected by increased number of superficial roots, may pose a new and difficult problem.

In this respect, the effect of soil amelioration on root system may be suggestive. Drainage of paddy field has been shown to exhibit a considerable contribution to the yield increase of rice. Drainage is effective not only in increasing the number of elongated crown roots, but also in increasing the number of crown roots penetrating deeply through the subsoil which was made to be porous by drainage[6]. It is probable that such deeply penetrating roots might take an important part in supporting higher yields.

On the basis of these findings on root systems, the authers at present are laying special emphasis on the role of soil conditions for the improvement of rice cultivation in

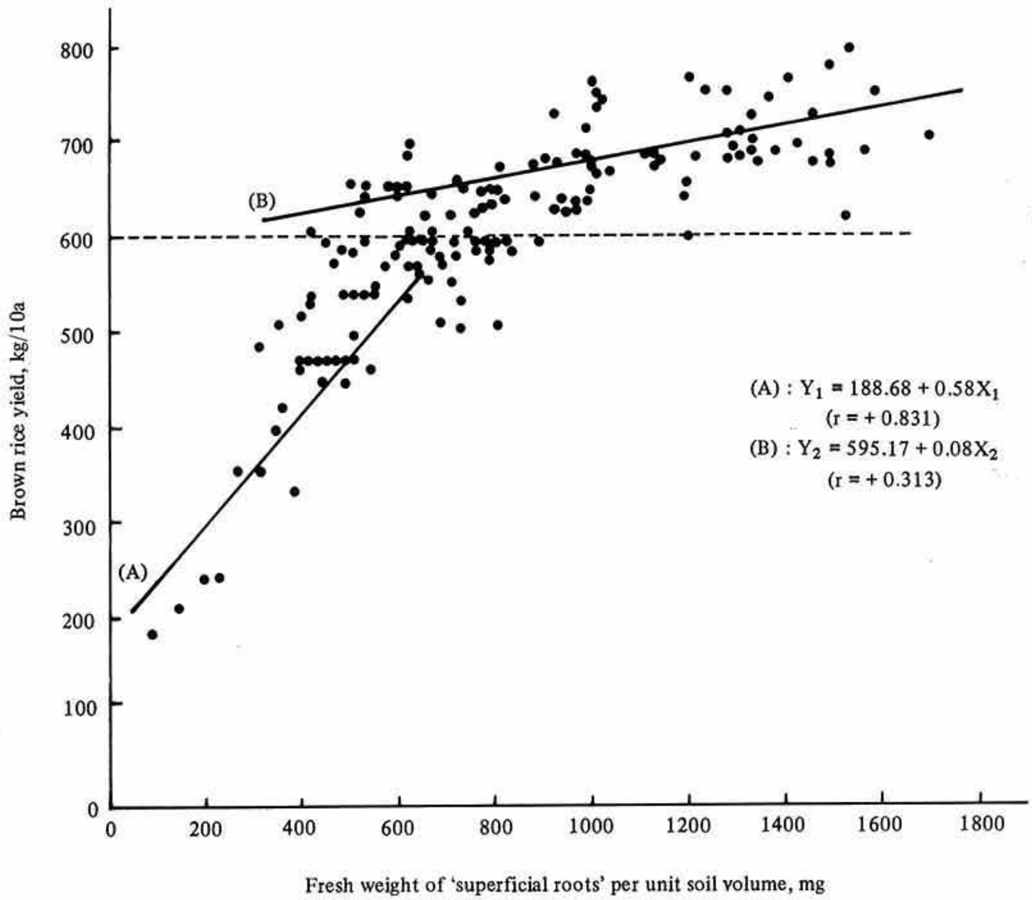


Fig. 4. Relationship between brown rice yields and fresh weight of 'superficial roots' contained in a unit soil volume (100 cc).

Each dot in the figure indicates each field where paddy yield and weight of superficial roots were measured.

Japan. Further analytical works on roots in highly productive fields will be expected to make a great contribution in this field of research.

## References

1) Kawata, S. et al.: Studies on root system formation in rice plants in a paddy. *Proc. Crop Sci. Soc. Japan*, 32, 163–180 (1963) [In Japanese with English summary].

2) Kawata, S., Harada, J. & Yamazaki, K.: On the crown root primordium formation in the stem of rice plants. *Proc. Crop Sci. Soc. Japan*, 41, 296–309 (1972) [In Japanese with English summary].

3) Kawata, S. & Soejima, M.: On superficial root formation in rice plants. *Proc. Crop Sci. Soc. Japan*, 43, 354–374 (1974) [In Japanese with English summary].

4) Kawata, S. & Harada, J.: On the development of the crown root primordia in rice plants. *Proc. Crop Sci. Soc. Japan*, 44, 438–457 (1975) [In Japanese with English summary].

5) Kawata, S., Soejima, M. & Tabuki, R.: Effect of dressing of nitrogen fertilizer in the formation of superficial roots of rice plants. *Jap. J. Crop Sci.*, 46, 254–260 (1977) [In Japanese with English summary].

6) Kawata, S., Katano, M. & Yamazaki, K.: Root system formation in rice plants in ill-

drained and well-drained paddy field conditions. *Jap. J. Crop Sci.*, **46**, 261–268 (1977) [In Japanese with English summary].
7) Kawata, S. & Katano, M.: Effect of water management of paddy fields on the direction of crown root growth and the lateral root formation of rice plants. *Jap. J. Crop Sci.*, 46, 543–557 (1977) [In Japanese with English summary].
8) Kawata, S., El-Aishy, S. M. & Yamazaki, K.: The position of 'stunted roots' in rice plants taken from the actual paddy fields. *Jap. J. Crop Sci.*, 47, 609–616 (1978) [In Japanese with English summary].
9) Kawata, S., Soejima, M. & Yamazaki, K.: The superficial root formation and yield of hulled rice. *Jap. J. Crop Sci.*, 47, 617–628 (1978) [In Japanese with English summary].
10) Kawata, S., El-Aishy, S. M. & Yamazaki, K.: The effects of several environmental factors on the 'stunted root' formation in rice plants. *Jap. J. Crop Sci.*, 48, 107–114 (1979) [In Japanese with English summary].
11) Kawata, S., Sasaki, O. & Yamazaki, K.: On the lateral root formation in relation to the diameter of crown roots in rice plants. *Jap. J. Crop Sci.*, 49, 103–111 (1980) [In Japanese with English summary].
12) Yamazaki, K., Katano, M. & Kawata, S.: The relationship between the number of ears and the number of crown roots on a hill of rice plants. *Jap. J. Crop Sci.*, **49**, 317–322 (1980) [In Japanese with English summary].

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