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Root System Formation and Its Relation to Grain Yield in Rice Plants

Koou YAMAZAKI*

INTRODUCTION

In recent years, increasing interests have been concentrated to root researches in a wide range of disciplines, i.e., plant physiology as well as ecology, agronomy, forest science and so on. This is because the development of researches on above-ground parts of plants has enevitably necessitated more knowledges on terrestrial parts, for better understanding of each plant as a whole. On such a background, a new international society was established several years ago in Europe, that is, International Society of Root Research(ISRR). The aim of the society is to increase mutual communication among root researchers of the world and to contribute to further development of this field of researches throuhg their international cooperation. At the end of August 1988, the first world-wide symposium entitled "Plant roots and their environment" was held at Uppsala University in Sweden. More than 200 root scientists from all over the world participated the symposium and it was very successful. However, unfortunately the information was not well recognized in Korea, and it was a regret that only a few researchers including me could attend the symposium from Asian countries. Since I am now a councillor of the society as a local correspondent, any questions on the society will be welcome. The next symposium is expected to be held in 1991 in Austria.

Now returning to the present subject, I will mention to some extent a part of research works hitherto been carried out in our laboratory. The researches on rice roots in our laboratory started about 35 years ago, under the leadership of late Professor Kawata. Since I had been engaged with his research project from its beginning and since I succeeded his position and the project after his retirement, I am responsible to all what I will state here.

DEFINITION AND TERMINOLOGY

At first, I will explain several definitions or designations we are using for describing rice morphology. We assume a rice shoot being composed of a vertical continuum of "shoot units" (abbreviated as SUs) (Kawata et al., 1963). Each SU comprises a leaf, a subjacent stem segment and a tiller bud at its base(Fig. 1). From each SU, except several uppermost SUs with elongated stem segments, there appear two groups of primary roots, the upper and the lower ones, respectively, demarcated by their positions on each stem segment. The concept of shoot unit is almost similar to that of phytomer, phyton or leaf-internode unit proposed by many researchers for various purposes. Although such concepts are not so familiar as the node-internode concept commonly used, they are very convenient when

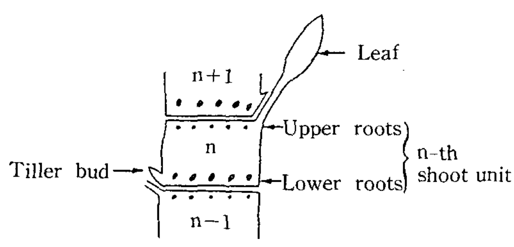

Fig. 1. Schematic expression of a shoot unit. (cf. Kawata et al., 1963)

* Faculty of Agriculture, the University of Tokyo, Japan

developmental relationships among different organs are investigated. Recently, a new evidence supporting the concept was presented (McDaniel and Poething, 1988).

Terminology of roots is a matter of much confusion, which was discussed in the ISRR symposium without getting any clear conclusions. For the moment, I will call the one root provided in rice seed as seminal root, and other roots which later appear directly from stems as primary roots, which are botanically a kind of adventitious roots. Secondary roots, tertiary roots and so on are defined as the branch roots appearing according to these orders on their parent root axes, respectively.

DEVELOPMENTAL PATTERN OF VARIOUS ORGANS

In rice plants, close relations have ever been found among growth and development of various organs. It might be well aware that a regular tillering pattern does exist in rice plants, which was first clarified by Katayama (1951). When leaves are numbered from base of a shoot, he found that the emergence of arbitrary n-th leaf occurs always synchronously with tiller emergence from the (n-3)-th leaf axil. According to our concept of shoot unit, it means the tiller emergence from the (n-2)-th SU, at the time of leaf emergence of the n-th SU (Fig. 2). A similar pattern exists in the case of primary root development. We have clarified that the n-th leaf emergence is quite synchronous with the initiation of the primary root primordia in the same n-th SU, and also with primary root emergence of the (n-3)-the SU (Fig. 2) (Kawata et al, 1963). Such regular pattern of development between primary roots and leaves is maintained throughout vegetative growth period of the plants, irrespective of the shoot being a main one or tillers.

As a plant grows, the number of tillers as well as primary roots increase according to the pattern just mentioned. The number of primary roots per hill finally reaches to about 700~1000, sometimes more than 2000, under the conditions of Japanese paddy fields (Kawata et al, 1978a). Such large number seems to be a peculiar characteristic of rice as compared with other gramineous crops. It may be a sort of adaptation of rice plants to submerged paddy conditions they grow.

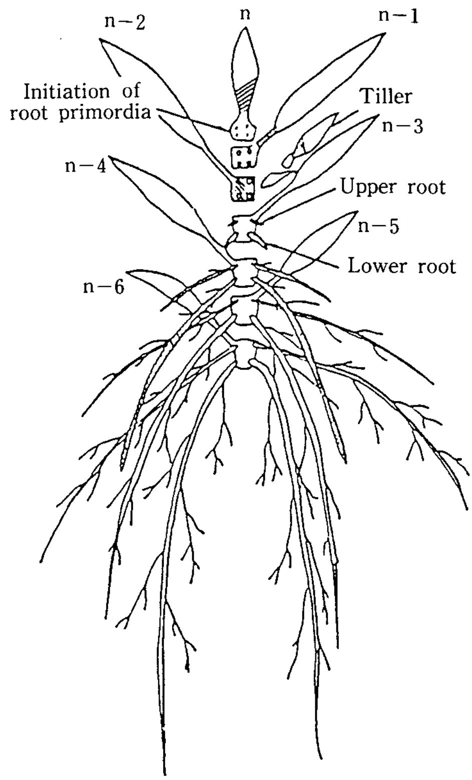

Fig. 2. Diagram showing the successive development of shoot and root in rice plant. Tillers below the (n−2)-th SU are omitted. (Yamazaki, 1989)

GROWTH AND FORM OF PRIMARY ROOTS

After emergence, a primary root elongates rapidly at first and the growth rate decreases gradually, ceasing its growth at about 4-th SU below (Figs. 2, 3). Growth duration of one primary root is estimated about 20 to 30 days after its emergence. During the growth of primary root, secondary roots appear from its base acropetally. Most of them remain thin and short,

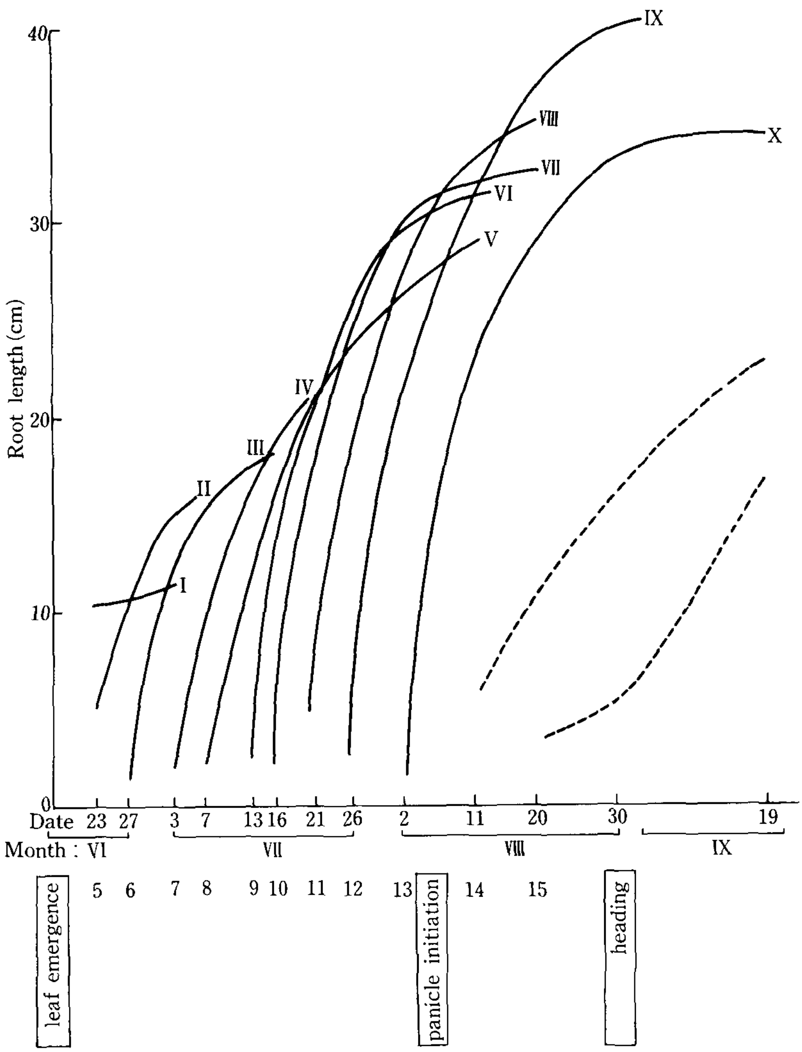

Fig. 3. Growth curves of lower primary roots in each SU(I ~XI).
XI and XII include estimated values. The 15th is the flag leaf. (Kawata et al., 1963)

and their averge density on 1 cm of primary axis is about 25. Among them, one or two become thick and long, forming tertiary or higher order branch roots (Kawata and Shibayama, 1966).

The primary roots exhibit much diverse forms in length, thickness and branching habit (Fig. 4) (Kawata et al., 1963). Usually the ones appearing at earlier growing stage of the plant are thin and short, while the ones growing in later stages become longer and thicker. The longest ones are formed near to the panicle initiation stage (Fig. 3, 4). In each SU, the lower primary roots are thick and long, while the upper ones are comparatively thin and short. Such distinction is more eminent among the later formed primary roots (Fig. 4). The primary roots formed after the panicle initiation stage tend to show a variety of forms (Fig. 5). Although their basal dimeters are thick, someones attenuate remarkably towards the tips and remain short, characterized by abundant branching. Someones appearing in this stage stop growing soon after their emergence and remain stunted within 5 cm in final length. Abundant formation of such stunted roots is

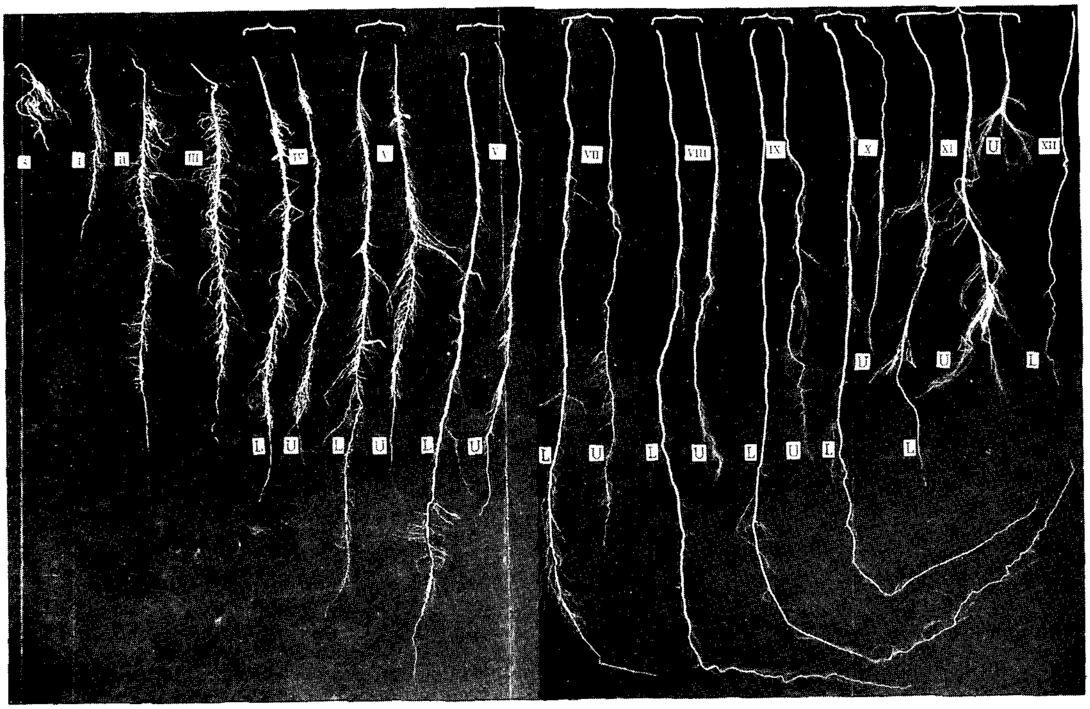

Fig. 4. Mature states of primary roots formed on successive SUs (I ~XII). S : seminal root, L : lower root, U : upper root. (Kawata et al., 1963)

another characteristics of rice root system.

ROOT SYSTEM FORMATION IN GENERAL

A rice root system is framed up by primary roots of various forms just mentioned. During the plant growth, the root system gradually spread deep and wide by the successively formed primary roots with increasing length and diameters (Fig. 6) (Kawata et al., 1963). At the heading stage, the root system attains its maximum size, and through this stage or hereafter, the primary roots predominantly grow in horizontal directions, making up the so-called "root mat" just below the soil surface. The branching of these superficial roots continues in later ripening stage.

It is commonly believed in many textbooks, that roots have positive geotropism and grow vertically. However, this rule can not be generalized in actual fields. Everyone well knows that roots have ability to grow in various directions, thus making the whole root system wide and deep. In this connection, we found a close relation between the basal diameter and the growing direction of each primary root (Fig. 7) (Yamazaki et al., 1981). In general, the thick primary roots tend to grow vertically, while the thinner ones more horizontally. Although the mechanisms controlling such phenomena are still obscure, the primary roots with various diameters are formed during the plant growth, and they grow into various directions as mentioned before, resulting in the whole root system spreading wide and deep into the soils.

ENVIRONMENTAL FACTORS CONTROLLING FORM OF ROOT SYSTEM

The forms of root system varies remarkably according to environmental conditions they grow or genetical properties as well. Abundant application of nitrogen fertilizer restricts the root system within a limited soil volume, though the number

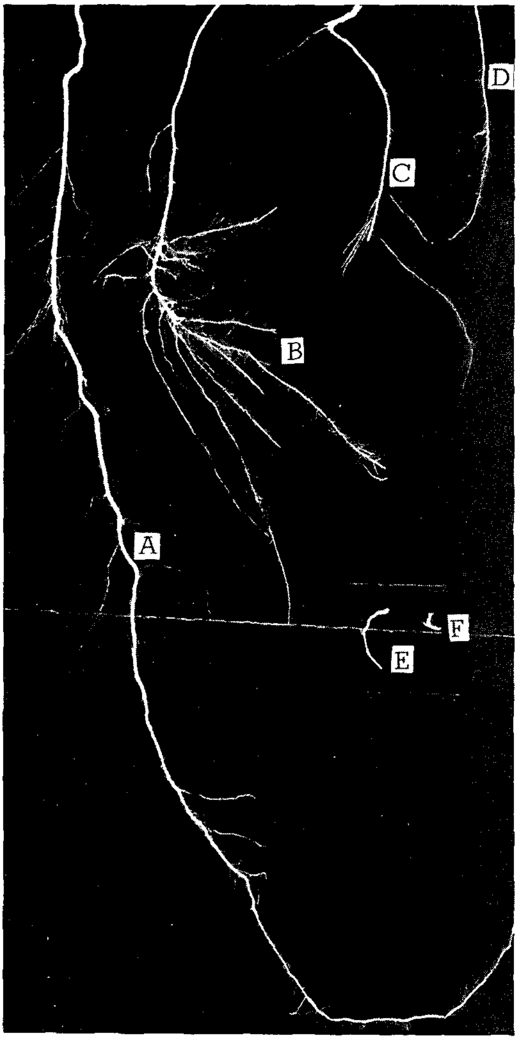

Fig. 5. Various forms of primary roots of the -th SU. A : normally grown one, B~D : malformed ones, E, F : stunted ones. (Kawata et al., 1963)

of primary roots increase and their branching is accelerated (Fig, 8) (Kawata et al., 1977a). The ways of application of nitrogen fertilizer also affect root system formation. Repeated topdressings make the whole root system to be a more shallow one (Kawata et al., 1977b). On the other hand, abundant application of organic manure makes the root system to spread deep and dense (Kawata and Soejima, 1976), though the mechanism underlying in this phenomenon is not clearly known. Water management in paddy fields is another factor controlling the form of root system (Fig. 9) (Kawata and Soejima, 1977). Root sytem formed under continuously submerged condition becomes shallower, while under intermittently irrigated condition, a well developed root system is formed. Mid-season drainage makes the root system just intermediate one mentioned above. There are many other factors controlling the form of the whole root system. Well drained paddy fields with developed subsoil structures accelerates deeply growing root systems (Kawata et al., 1977c). Hard plow pan resulting from the usage of heavy machinery inhibits root penetration through the pan. Mutual shading due to over-luxuriant growth of aerial parts of plants also makes the root systems spread within rather shallow horizon. Almost the same phenomenon is observed when the plants were artificially shaded (Mawaki et al., 1987).

RELATION BETWEEN GRAIN YIELD AND ROOT SYSTEM

The last problem of my presentation is how these variations in the form of root system influences the grain yields. At first, it should be pointed out that the number of elongated primary roots per plant or hill, excluding stunted roots, is highly correlated with the numbers of fertile tillers, flowers and eventually the grains of the plant (Fig. 10) (Yamazaki et al., 1980). It is estimated that one primary root corresponds roughly to two ripend grains or 40 mg of ripened grain weight (Yamazaki and Harada, 1984). These figures of course varies according to the form of root systems mentiond before.

Other quantitative characters of root system also have intimate relations with grain yields. We took core samples of surface soils from about 150 paddy fields located in various areas of Japan, and fresh weight of superficial roots per unit soil volume were compared to the yields of each field (Fig. 11) (Kawata et al., 1978). The results show that the quantity of superficial root mass is highly correlated with the grain yield, as far as

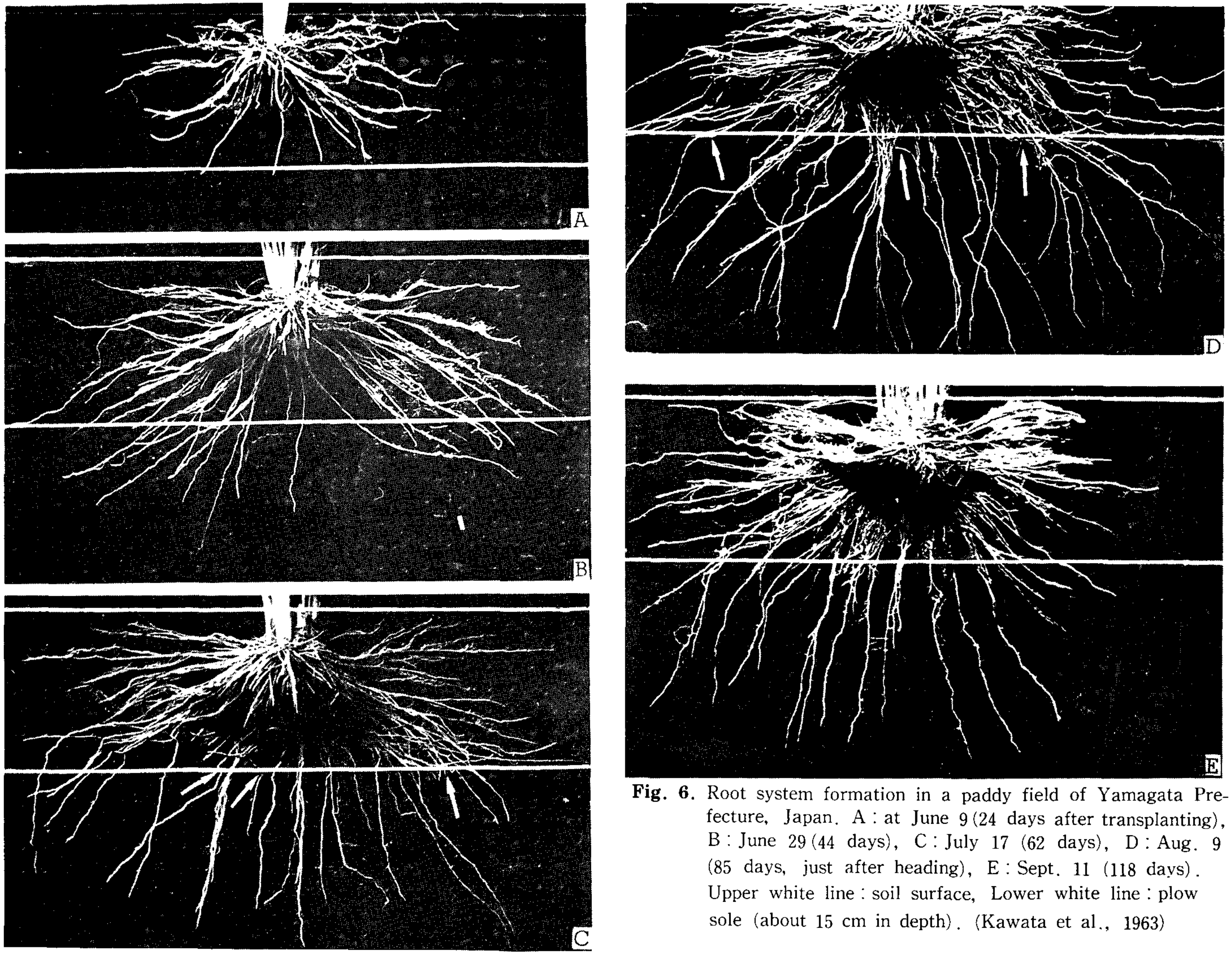

Fig. 6. Root system formation in a paddy field of Yamagata Prefecture, Japan. A : at June 9 (24 days after transplanting), B : June 29 (44 days), C : July 17 (62 days), D : Aug. 9 (85 days, just after heading), E : Sept. 11 (118 days). Upper white line : soil surface, Lower white line : plow sole (about 15 cm in depth). (Kawata et al., 1963)

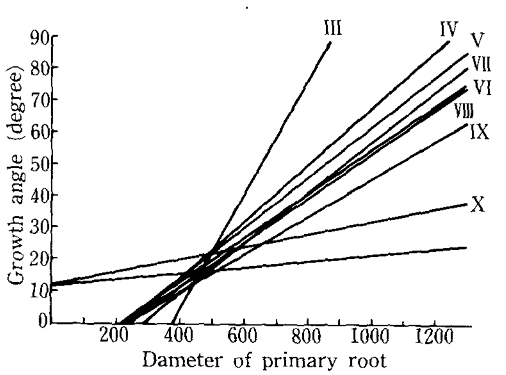

Fig. 7. Regression lines between basal diameters of primary roots and their growing directions in each SU. III～ : SU number, in which all corresponding SUs of tillers of the plant are included. Growing angle : degree from soil surface. (Yamazaki et al., 1981)

the fields concerned remain in low yielding levels. *In other words,* the quantity of root mat is proportional to grain yield at this production levels. However, in the fields of high yielding levels, such correlation becomes obscure. This fact suggests that not only the superficial roots but also deeply developed root system might play an important role in increasing grain yields. In this connection, we designed various experimental plots having different yielding levels by modifying quantities of nitrogen application (Morita et al., 1986). The results show that high yields are closely associated with the increase in the percentage of deeply grown primary root number (Fig. 12). Shading treatment during panicle formation period is also very interesting. Under

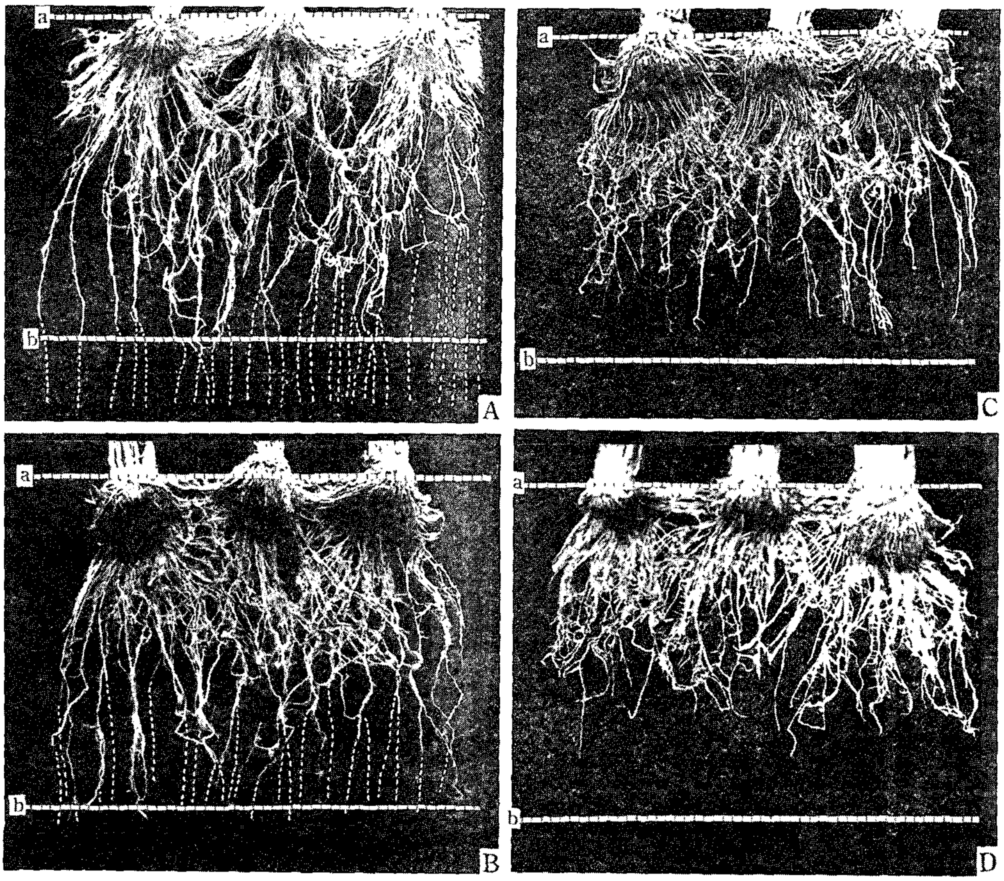

Fig. 8. Root systems formed under different nitrogen (N) levels. A : no N, B : 8 kg N/10 a, C : 16 kg N/10 a, D : 24 kg N/10 a. a : soil surface, b : 50 cm depth. Broken lines show the roots cut off during procedures. (Kawata et al., 1977a)

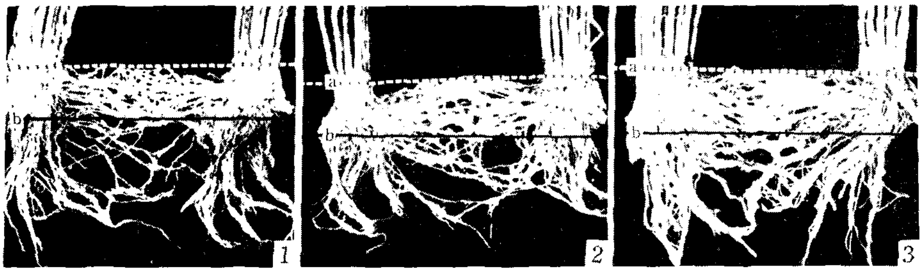

Fig. 9. Root systems formed under different water management. 1 : condinuously submerged plot, 2 : drained-in-midseason plot, 3 : intermittently irrigated plot. a : soil surface, b : 5cm depth. (Kawata and Soejima, 1977)

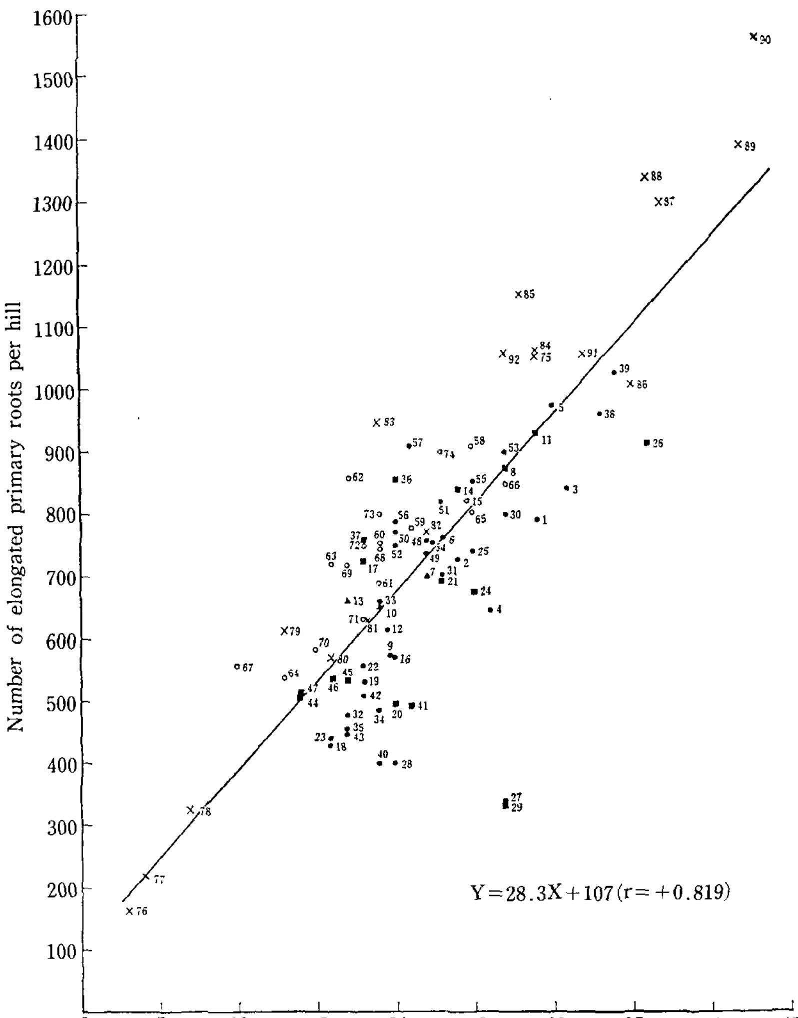

Fig. 10. Numerical relationship between elongated primary roots and panicles. Symbols and numbers in the figure show different growing conditions. (Yamazaki et al., 1980)

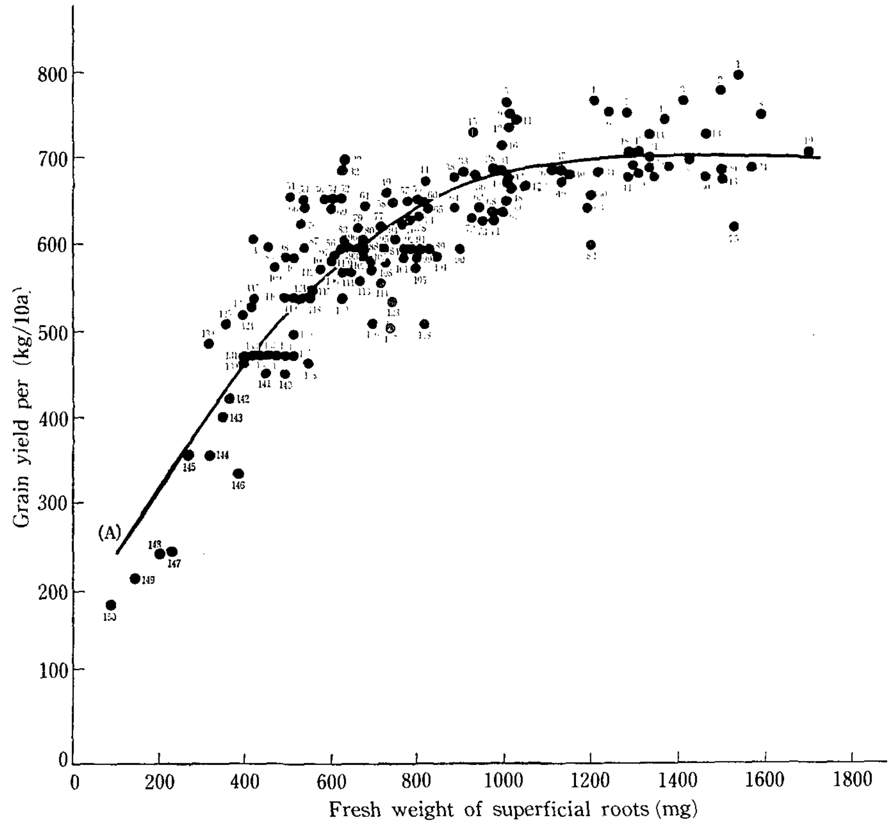

Fig. 11. Relationship between grain yields and fresh weights of superficial roots. (A) : anestimated curve of the relationship. Numbers in the figure show different paddy fields. Superficial roots were collected from soil cylinder with 5cm diameter and 5cm height. (Kawata et al., 1978)

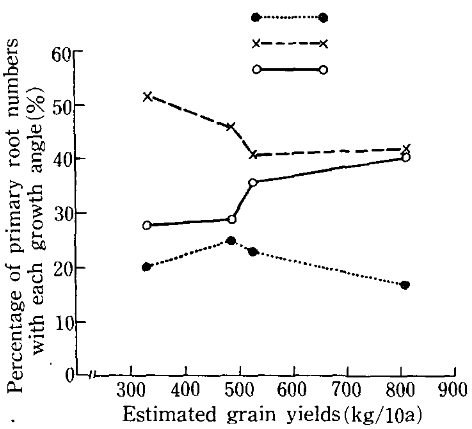

Fig. 12. Relationship between growth direction of primary roots and estimated grain yields. (Morita et al., 1986)

the shading condition, root system becomes shallower with much superficial roots, and although no difference is obseved in flower number between treated and control plots, grain yield decreased significantly in the treated plots (Mawaki et al., 1987). Recently, we compared the root systems of Korean cvs. bred through japonica-indica hybridization and Japanese common cvs. (Harada et al., 1988). The results show that the Korean cvs. usually produce many thick primary roots with much branching, especially in later growing stages of the plants, as compared to Japanese cvs.

These findings suggest the importance of thick and well branched roots, which might have grown deeply, and may also in parts account for the high yielding ability of the Korean cvs.

CONCLUSIONS

The activity of roots is another important characteristics in evaluating the function of root system relating to the yield formation. However, since the convincible results concerne are scarce, I had to restrict the topics only to the morphological point of view. Further development of such kind of research may require the cooperative works of wider disciplines. At present, we believe that abundant formation of primary roots with much branching and with deeply growing habit is the keypoint for attaining high yielding levels in rice cultivation.

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