7. THE ROLES OF ROOT SYSTEMS OF RICE PLANTS IN RELATION TO THE FUNCTIONS OF AERIAL PARTS

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In 1949, the Asahi Shimbun Publishing Company started to hold anual contests for Japan's best rice growers. The aim of this project was to develop and disseminate high-yielding techniques and to reward the farmers who obtained the highest yield of rice. To achieve this goal, many rice experts were requested to participate in the project by conducting close examination of the techniques.

The techniques adopted by the prize-winners were not the same. They used different varieties and methods of culture under diverse climatic and edaphic conditions.

However, the methods have some common features in their techniques. We first notice that the paddy fields have been improved by deep tillage, admixturing of soil, under drainage, and application of farmyard manure. We next note that water management such as an intermittent irrigation and a heavy temporary drainage are commonly adopted in most of the prize-winners' techniques.

The significance of these techniques may be attributed to the maintenance of physiological function of the root. However, it has not been made clear yet what the root function or the root activity really is. The object of this report is concerned with the roles of root systems of rice plants in relation to the functions of aerial parts.

Root system formation in rice plants

Katayama (1951) carried out very intensive observations on the leafing and tillering processes of rice plants. He established a rule for leafing and tillering and proposed the theory of synchronous leafing.

Fujii (1961) conducted experiments on the rooting behavior in relation to the growth of aerial parts in rice plant. He found that the roots of a certain node and the upper third leaf from the node emerged and elongated simultaneously and that high growing correlation between the roots and leaves in successive nodes was maintained.

For example, when the fourth leaf on the main culm develops, the leaf of the first primary tiller would develop and the roots from the first node of the main culm would develop simultaneously. When the fifth leaf of the main culm develops, the first leaf of the second primary tiller, the second leaf of the first primary tiller and the root from the second node of the main culm would develop at the same time (Fig. 1). The number of the roots as well as the vascular bundles in the leaf sheath at the successive nodes indicated high correlation.

The profile of the root sphere in the paddy soil may differ with the growth stage ; at the primordial initiation stage, it may be oblong while after that stage it may be ovoidal consisting of two parts ; i, e, a thickly rooted oblong sphere at the peripheral layer of the soil and a more or less loosely rooted sphere at a deeper layer.

The first part is called "superficial roots" which emerge horizontally from the nodes at an angle of more than 90° and spread over into the upper layer of the soil, like a net

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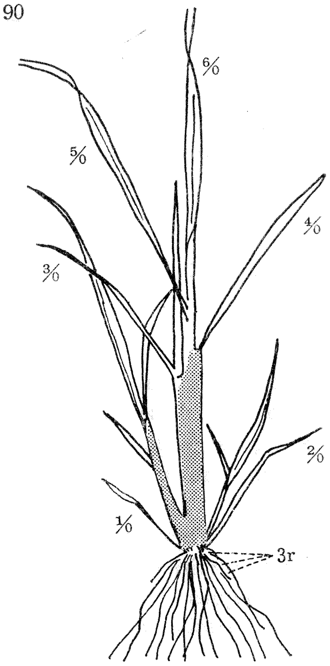

Fig. 1. Root and leaf development in rice plants. Note : 3r ; third crown root. (Fujii 1960)

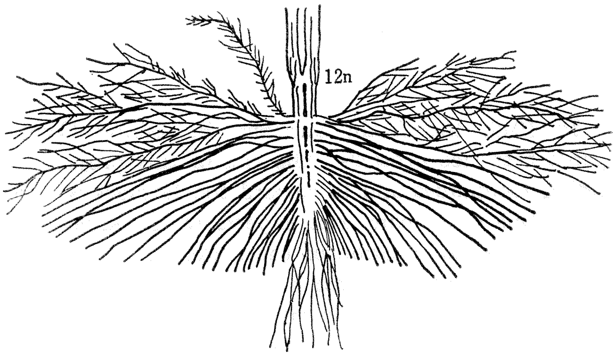

Fig. 2. Root system in rice plant. (Fujii 1960)

having numerous branch roots. The second part is called crown roots which emerge befor the primordial initiation stage and spread into the deeper layers of the soil (Fig. 2).

Mori (1960) conducted an investigation microscopically on differential and developmental patterns of tissues in crown roots of rice plant. The region of cellular differentiation and development in a root is a segment from tip to 300μ level. The observed results of these patterns were summarized diagrammatically in Fig. 3.

Kawata et al (1963) found that shoots of rice plants were designated as "shoot units" each with an apical leaf, a basal bud and upper and lower root zones (see Fig. 4). Upper and lower primary roots appearing on a shoot unit emergd essentially at the same time. Lower (basal) roots of a shoot unit are usually larger in diameter than the upper (apical) ones

Kawata and Ishihara (1959) discovered that root hairs were formed in the short cells of the epidermis of the root with polarity : when the soil of the paddy field was in the process of oxidation, root hairs were found at farther distance from the root tip than in the reductive soil and furthermore they were numerous in number and longer in lenght. On the contrary, their formation was poor when the soil was reductive.

It was reported by many investigators (Arikado, 1953. Fujii, 1953) that the development of the lacunae of rice roots growing under anaerocic soil conditions was remarkable as compared with that under aerobic soil conditions. It was assumed that oxygen needed for root respiration would be supplied mainly by leaves via stems and lysigenous lacunae when the rice plant was kept in anaerobic soil.

On the other hand, an investigator (Kawata, 1956) asserted that the physiological role of lysigenous lacunae of rice plant roots should be re-examined from the formation of lysigenous lacunae had relations with the development of lateral roots, that the formation of lateral roots in the soil of paddy field was generally accelarated when it was in an oxi-

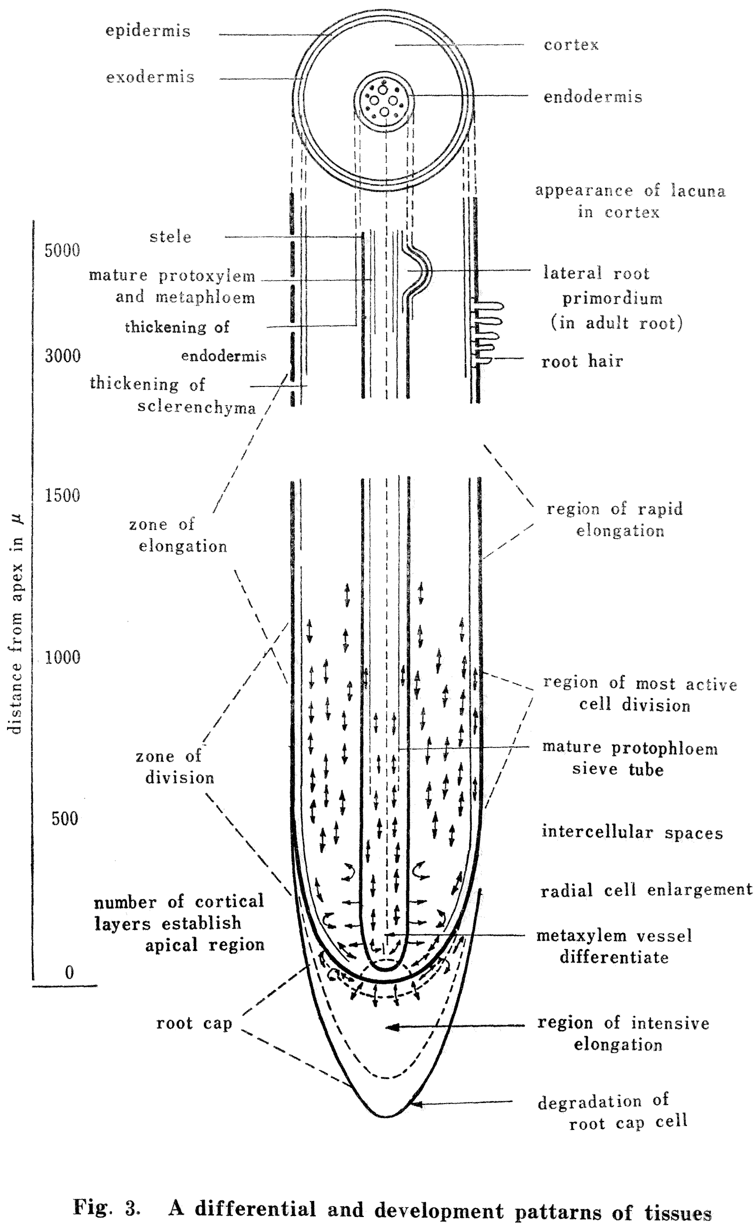

Fig. 3. A differential and development pattarns of tissues in crown roots of rice plant (Mori 1960)

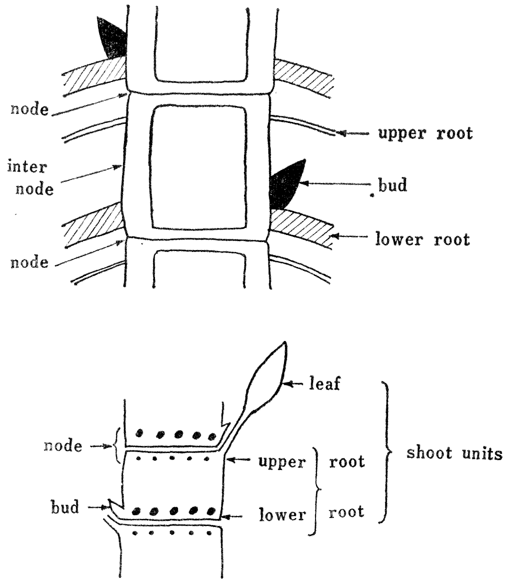

Fig. 4. Diagram of "shoot units." in rice plants
(Kawata et al 1963)

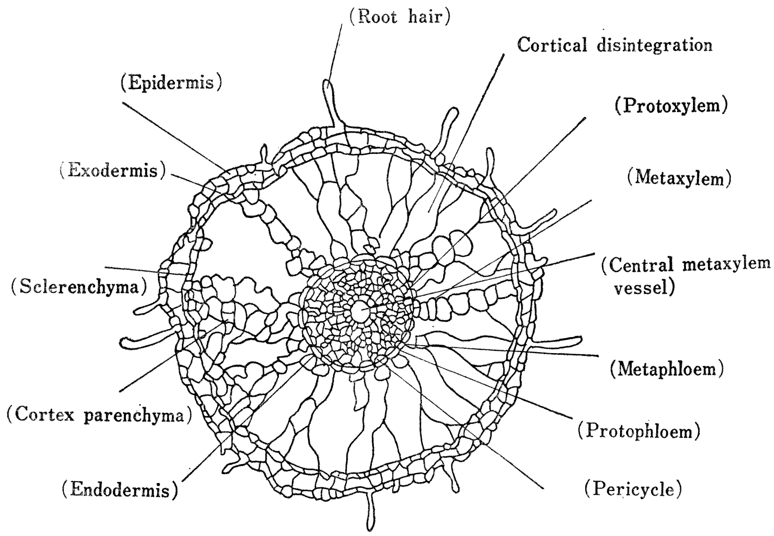

Fig. 5. Cross section of rice root.
(Yoshida 1968)

dative state and that the development of lacunae, on the contrary, was slowed down when the soil was reductive.

Kono (1968) assumed that the emergence of cortical disintegration and the initiation of of lateral roots had a close relationship with each other in time and position, and that the enlargement of cortical disintegration was restricted by the velocity and the volume of the growth of lateral roots.

Therefore, whether the development of cortical disintegration will be promoted in reductive soil condition or in oxidative soil conditions, depends mainly on the growth of lateral root in volume or velocity (Fig. 5).

Physiological function of rice roots

Physiological functions such as the uptake of nutrients and the respiration per root may be relatively estimated by taking into due consideration the development of root, the rate of root tip elongation and the root colour (Tables 1 and 2).

The amount of nutrient absorption and the development of roots throughout the growth period of rice plants grown in paddy field soils were made clear by Inada (1967) and are shown in Fig. 6. The amount of nitrogen absorption is coincident with the number of newly developed roots. This indicates the fact that nitrogen is absorbed efficiently from the soil by new roots. Postassium and phosphorus absorption shows a close relation in the number of the new roots, but the absorption is compatible chiefly with the total fresh weight of the root apexes of new roots or relatively younger roots approximate to new roots. However, the absorption reaches a maximum several days later than nitrogen absorption. This can be ascribed to the fact the absorption is done also by the parts other than root apexes. In contrast to this, the absorption of iron, magnesium and sulfate reaches a maximum about 10 days later than the day on which the new roots and the total fresh weight of root apexes reach a maximum. The absorption of silica and manganese reaches a maximum about 20 days later. From these results, it is assumed that the absorption of silica and manganese is made also by fairly older parts other than young root apexes.

Yamada and Ota (1958) reported that the nitrogen absorption by roots coincided well with the respiration in roots at the respective plant growth stage (Fig. 7).

Table 1. Relation between root age and morphological characters of root (Yamakawa and Kishikawa 1957)

Exp. No.	a	b cm	c mm	d mm	e cm	f %	g mm	h mg
1	5	5.0	0.628	0.591	3.86	77.2	0.5	2.3
2	8	12.4	0.623	0.489	3.30	26.6	2.4	3.5
3	11	18.5	0.617	0·407	2.64	14.3	3.9	4.8
4	14	21.6	0.638	0.303	2.06	9.5	4.8	5.9
5	17	20.9	0.615	0.264	0.09	0.4	5.4	5.6
6	20	20.3	0.635	0.261	0.13	0.6	5.3	5.6
7	23	21.0	0.648	0.270	0.10	0.5	5.4	5.7
8	26	17.9	0.636	0.251	0.16	0.9	5.2	4.1
9	29	15.6	0.633	0.240	0.09	0.6	5.1	3.5
10	32	14.9	0.626	0.230	0.19	1.3	5.1	3.6

Notes : a. Root age ; days after root emergence, b. Root length, c. Diameter in base of root, b. Diameter of root tip, e. Root length from tip to region which branching root emerged, f. Root length from tip to region which branching root emerged/root length × 100, g. Length of branching root, h. Dry weight of root.

Table 2. **Relation of root age, uptake of NH_4-N and water, and respriation**
(Yamakawa and Kishikawa 1957)

Item	Exp. No. 1	2	3	4	5	6	7	8	9	10
	Day after root emergence 5	8	11	14	17	20	23	26	29	32
Uptake of NH_4-N NH_4-Nmg/1/24h/10roots	1.8	4.6	5.8	3.0	1.6	1.5	1.0	0.5	0.5	—
NH_4-Nmg/1/24h/100mg dry weight of root	7.6	13.3	12.1	5.2	2.9	2.7	1.8	1.3	1 5	—
Uptake of water water cc/24h/10 roots	8.8	19.2	23.1	25.5	25.1	26.3	27.8	27.7	28.5	—
Water cc/24h/1gr dry weight of root	379	548	478	435	449	470	491	680	813	—
Dry weight of aerial parts, mg	80	121	143	195	218	267	326	356	410	434
Respiration O_2mg/1/24h/10 roots	13.0	15.2	19.8	12.7	9.4	7.9	8.2	6.5	5.1	5.6
O_2mg/1/24h/100mg dry weight of root	76.5	56.9	39.1	22.3	18.6	15.1	15.3	13.7	15.1	16.7

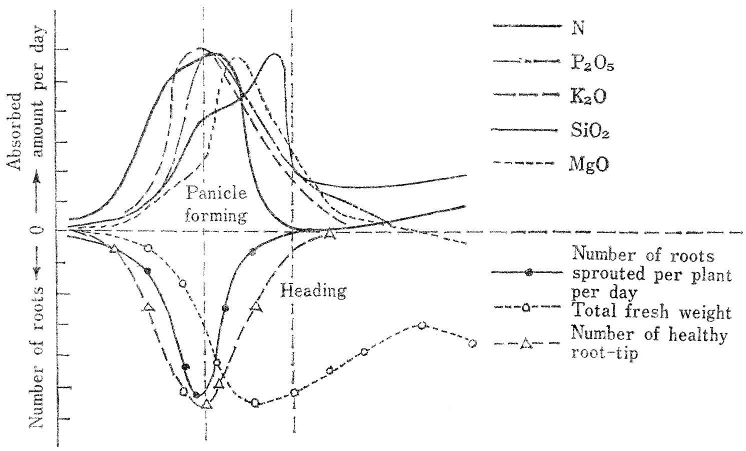

Fig. 6. Relation between nutrient absorption per day and number of roots, according the plant growth stages.
(Inada, 1967)

Inada (1967) gave and account of the physiological function of rice roots. During the growth period, the average age of roots on a plant is relatively young up to the young panicle formation stage, and young roots perform respiration at high rate absorbing a large amount of essential nutrients including nitrogen, potassium and phosphorus. The active growth of plant during this period seems to be supported by the respiration of TCA cycle →cytochrome-cytochrome C oxidase system in the root. After that stage, however, the root becomes older in the average age, and the respiratory rate goes down. In this period, considerable respiration via cytochrome-cytochrome C oxidase system is still maintained

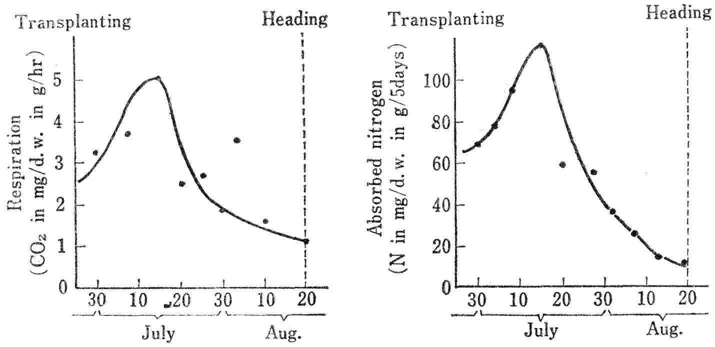

Fig. 7. **Relation between respiration in roots and nitrogen absorption by roots** (Yamada and Ota, 1958)

mainly in numerous, young rootlets bearing on older roots, which will be supporting an active absorption of nutrients during the reproductive stage. Ascorbic acid oxidase and/or peroxidase, which is activated with the aging of root may have a possibility of participating in the maintenance of such activity of roots and rootlets through the oxidizing action against the reduced soil condition.

Okajima (1960) reported that the specific characters which the young and old roots show respectively in water and salts absorption can be regarded as reflecting their difference in nutritional state in response to their growth between the two kinds of roots. Old roots are apt chiefly to take part in the absorption of water owing to their position and large absorption area. These roots which have advanced in growth and possess comparatively less nitrogen and potassium contents are low salt high-sugar ones. Young roots, on the other hand, constituting mainly of those in the process of cell division and elongation, are in the state of high-salt low-sugar with a higher nitrogen contents and they are high in oxidation activities.

Consequently, when the demand of a plant for water concentrates on the old roots and the quantity of water absorbed by the young ones is small, the absorption of inorganic nutrients by young ones ought to decrease in quantity. This is assumed to be the case of a phenomenon that young roots supply less water and nutrients to the plant in spite of their higher water and salts absorption capacity compared with older roots.

Root and top development in rice plant

The maintenance of proper balance between root and top growth is of very great importance. If either is too limited or too great in extent, the other will not thrive. The root must be sufficiently widespread to absorb enough water and nutrients for the stem and leaves, which, in turn, must manufacture sufficient carbohydrate for the maintenance of the root system.

Mori (1960) discovered that the relative growth of the root and top in rice plants may be expressed by the allometric formula,

$$y = dx^{\alpha}$$

where x is the dry weight of top, and y the dry weight of root, while b and α are constants. The constant α represents, the ratio of the logarithmic growth rate of root over that of top, and b the weight of the root when the top weighs one gram.

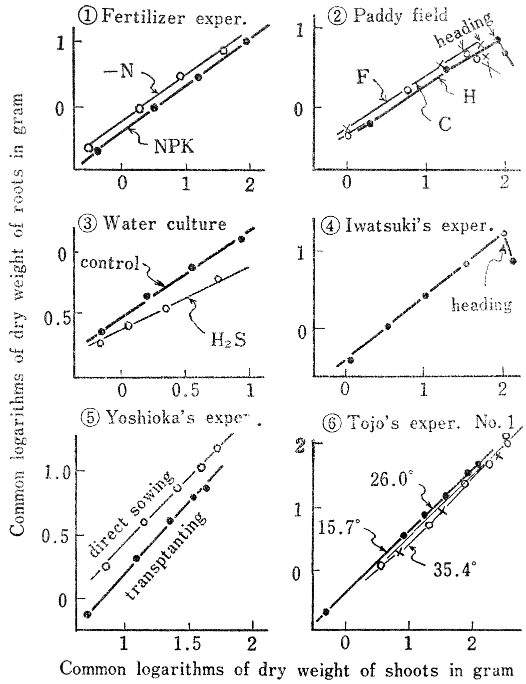

Fig. 8. Regression lines expressing the relative growth of root and shoot plotted on double logarithmic grid. (Mori 1960)

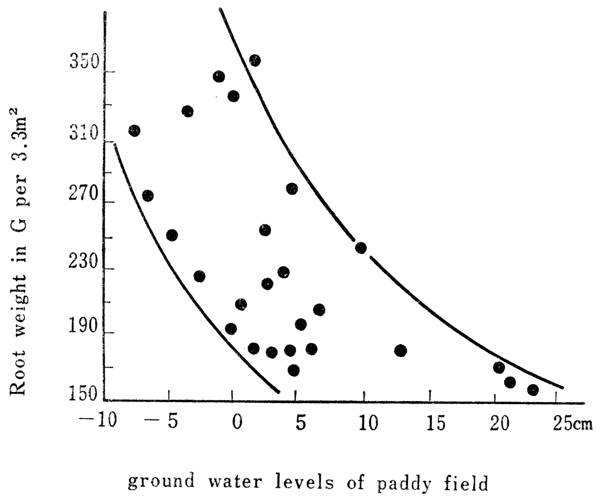

Fig. 9. Relation between root development and ground water levels of paddy field. (Yamada et al 1962)

The formula may also be written as log y=log b + α log x, so that when the measured values are plotted on a double logarithmic grid the points fall on a straight line. The value of α is therefore equivalent to the regression of log y on log x (Fig. 8).

Yamada et al (1962) investigated the root development on different ground water levels of paddy field. The root development was found to be better on a field where the ground water was at a high level (Fig. 6). On the contrary, lower the level of ground water in fields, the higher the grain yield.

On the other hand, Ogihara et al (1958) compared the root development of rice plants between the "akiochi" and healthy ones. The root development of rice plants did not show any difference between "akiochi" and the healthy ones until the young panicle formation stage from transplanting. After the heading stage, healthy roots developed more both at a depth and at the surface of soil, and the total amounts of roots was larger as compared with "akiochi" rice plants (Fig. 10).

Translocation of photosynthates to rice roots

Yoshida (1968) reported that the translocation of photosynthates from leaves to roots in rice plant commence from one hour after synthesis as sucrose, and that translocation reaches maximum at three to six hours after synthesis. At the young panicle formation stage, the amount of sucrose translocated from leaves to roots per day corresponded to 5-12 per cent of roots by weight.

Tanaka (1958) observed the translocation of photosynthates in rice plant by autoradiograph. Photosynthates of upper leaves translocated mainly to the developing leaves. On the contrary, photosynthates of lower leaves translocated principally to the roots.

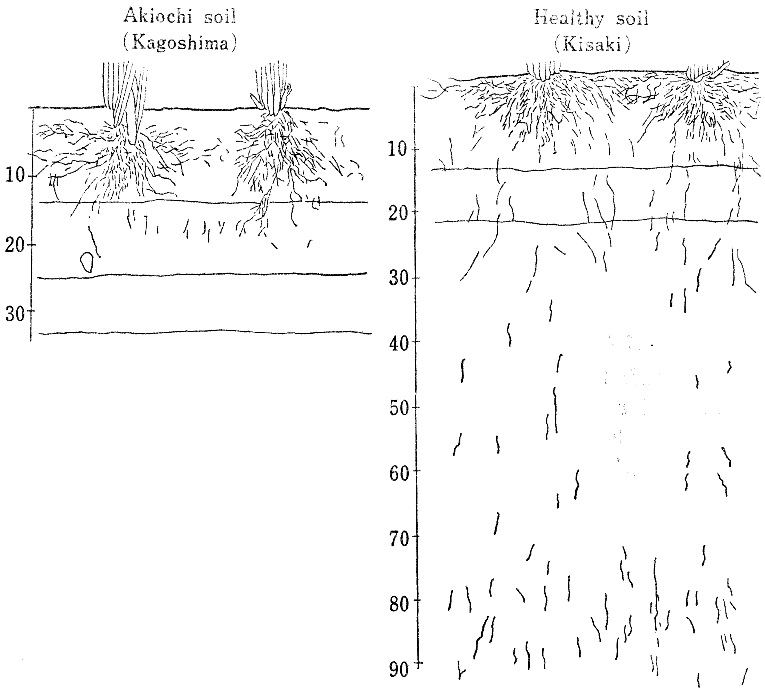

Fig. 10. Root systems of rice plants. (Ogihara et al 1958)

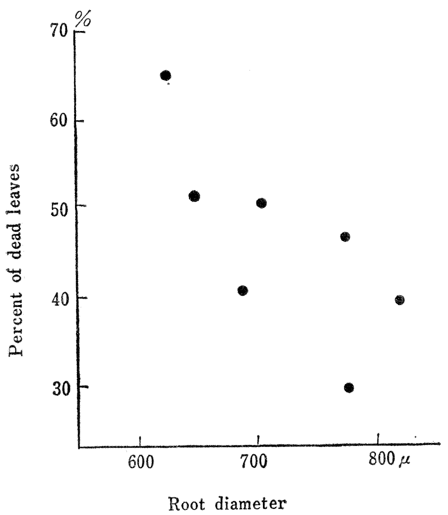

Fig. 11. **Relation between leaf senesence and root diameter in rice plants** (Nagai and Hirota 1958)

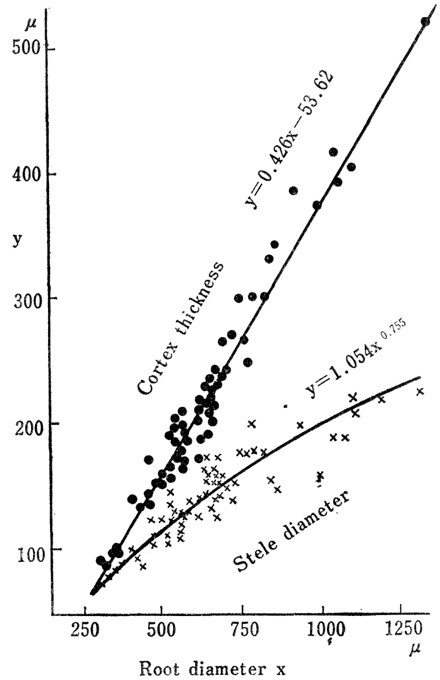

Fig. 12. **Regressions of the contex and the stele diameter on the root diameter** (Mori 1959)

Ota and Yamada (1958) investigated the translocation of photosynthates from aerial parts to roots in rice plant by using radioisotope under the different nutritional conditions. Silica and potasium played an important role in the translocation of photosynthates, and calcium deficient plant was decreased in the translocation of photosynthates to the roots.

Leaf senescence and the angle of leaf inclination in relation to physiological functions of roots.

Nagai and Hirota (1958) reported that among 280 rice varieties which had different resistibilities against soil reduction, there were also differences of root diameter. The more resistant the variety, the larger the root diameter (Fig. 11).

Mori (1959) recounted that variation of the root diameter was attributable chiefly to that of the cortex parenchyma (Fig. 12). Cortex parenchyma originate from lysigenous cavities concerned with the oxygen supply from top to root and the stele system relates to the migration of the nutrients and water absorbed. Thus, root diameter must regulate the physiological activity in roots, inclusive of the whole plant.

Park and Ota (1969) found that the α—Naphthylamine— oxidizing activity of rice roots was closely related with leaf senescence and the angle of leaf inclination (Fig. 13). The same results were obtained by Heu and Ota (1969) with the rice plants cultivated by the deep placement of top-dressing cultural method.

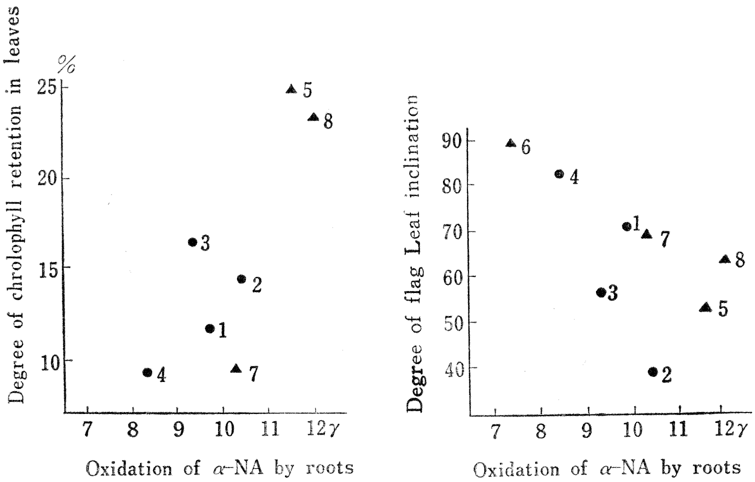

Fig. 13. **Leaf senescence and leaf inclination in relation to the root activity** (Park and Ota 1969)

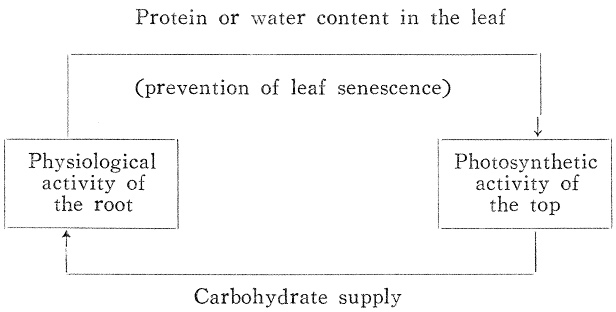

Fig. 14. A diagram on the interrelationships between photosynthetic activity of the leaf and physiological activity of the root. (Murata et al 1965)

Photosynthetic activity in relation to physiological function of roots

It has been suggested by Oritani (1962) that the amount of root has an intimate relationship in rice plants with RNA production through which the protein level in the leaf is thought to be regulated.

Murata et al (1965) reported in connection with the problem how to maintain the photosynthetic activity of rice plants in an ill-drained paddy field. Reduction in photosynthetic rate gave a drastic, retarding influence on the growth of the root, various treatments to give injuries to the root, resulted in reduction of photosynthetic activity which showed a close correlation with the respiratory activity of the root. The reduction in photosynthetic activity also indicated a close correlation with the protein contents of the leaf at an earlier growth stage, and with water contents of the leaf at a later growth stage, respectively. This was interpreted as a proof to show that the effect of root activity on photosynthetic activity was reflected by its influence on these processes. Fig. 14 was postulated to show the interrelationships between photosynthetic activity of the leaf and physiological activity of the root.

Discussion

S. K. De Datta, IRRI : Concerning Fig. 9 is it possible to develop a variety to have high a root weight even at low ground water level of rice fields? If so, it would be helpful to grow it as an upland variety.

Answer : In general, upland varieties have a deep root system compared with lowland ones for adaptation to drought.

M. Shafi, Pakistan : I would like to know why rice is grown under submerged conditions and not like wheat or barley.

Answer : This problem is very difficult to answer. It may be considered that the growth behavior of rice plant has been well adapted to submerged condition. For instance, rice roots have an oxidation activity of ferrous to ferric, and develop cortical disintegration. Also, submerged conditions have advantages, for example, they make it possible to save nutrients, or to avoid soil sickness often induced by continuous cropping.

M. Matsushima, Japan : You said there is a close correlation between the yield and root activity. But from my experiment I obtained the opposite results very often. How do you explain the facts?

Answer : The rice yield was closely related to the root activity at ripening stage, but not always. At early growth stage, root activity sometimes increased abnormally in an ill-drained condition.

Y. Murata, Japan : 1. At what stage is the root activity most closely related to grain yield? 2. Are there any differences in root activity in indica variety and japonica one?

Answer : 1. Most close relation was observed at ripening stage. 2. We do not have sufficient data to indicate difference in root activity between an indica variety and japonica one. In my experience, some of indica varieties tolerated to ill-drained condition.

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