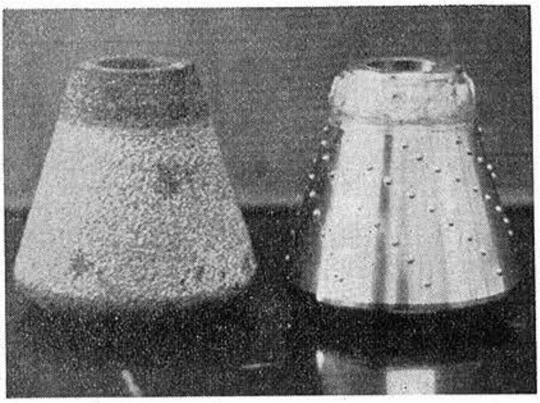

Fig. 8 Left : Cone of an Italian small sized milling machine
Right : Improved cone

Physiological Function of Rice Roots

K. INADA

Chief, 3rd labolatory of Physiology, 1st Division of Physiology, Department of Physiology and Genetics, National Institute of Agricultural Sciences

It is a well-known fact that the growth and yield of rice plant is much affected by the physiological function of the root. Therefore, various methods such as soil amelioration, improvement of fertilizer application methods, irrigation water control, etc. have been applied by cultivator to maintain the root activity, particularly for the later growth stages. However, it has not been clear yet what the root function or the root activity really is.

The present study was carried out in the period from 1957 to 1965 at Konosu branch of the National Institute of Agricultural Sciences for the purpose of making clear fundamental nature of physiological activity in rice roots by investigating the physiological char acteristics of roots classified by their age at various plant growth stages[3].

Rice plants (varieties used were mainly Nōrin no. 29 and Nōrin no. 25) were grown by soil- or solution-culture in pots or in the field. Classification of roots was made in relation to their age by a standard based on the length of the part on which rootlets occur to the full length of the root, that is, Class I: none, Class II : about 50 %, Class III : about 80 %, and Class IV : over 90 % in the ratio, respectively, as given in fig. 1. This standard corresponds well to the number of days after the root emergence, that is, Class I : within 3 days, Class II : 3 to 7 days, Class III : 7 to 14 days, and Class IV : more than 14 days, respectively.

The results obtained are summarized as follows.

Change in the root quantity according to the plant growth stage.

The number and fresh and dry weights of roots per plant increase with the growth of plant up to around the heading time, and then they decrease toward the late ripening stage as shown in fig. 2. According to the distribution of fresh weight (fig. 3) and the total accumulated length of roots of respective class, younger roots (Classes I and II) appear mostly at earlier growth stages with the maximum at about 20 days after transplanting. In contrast to this, the ratio of older roots (Classes III and IV) increases quickly after the young panicle formation stage, and almost all the roots convert themselves to Classes III and IV after heading.

The contents of dry matter and mineral components vary widely according to the age of roots. The younger the roots are, the lower the dry matter content and the higher the potassium content on dry weight basis, while the older the roots, the higher are the dry matter, iron and silicon contents[2,4].

The increase in the number of roots per plant followed a curve similar to that of the number of tiller, delaying by 5 to 10 days. The root-top ratio in dry weight reaches a peak at approximately 20 days after transplanting, then it sharply drops till just before maturing.

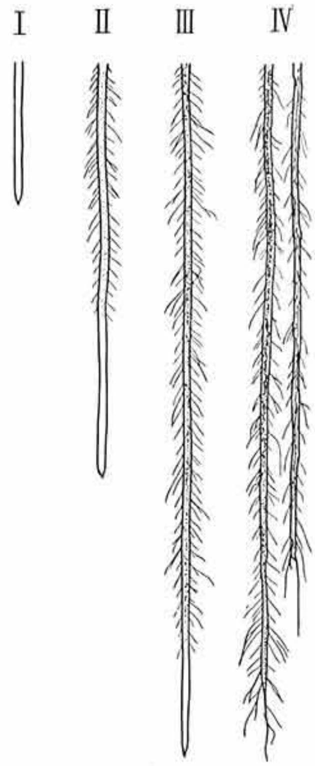

Fig. 1. Typical appearance of classified rice roots.

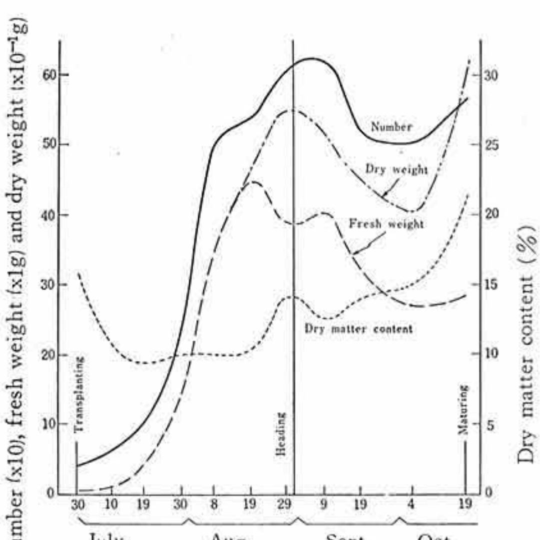

Fig. 2. Changes in the number, weights and dry matter content of roots per plant according to the growth stage.

Relation between the nutrient absorption and the age of roots.

From the comparison between the amount of nutrients absorbed per plant per day and the quantitative properties of roots according to the plant growth stage and comparison between the amount of nutrients absorbed per length or per weight of roots and the distribution of classified roots, it was suggested that the nitrogen absorption is mainly performed by roots of Classes I and II, potassium, by those of Classes I, II and III^-, and phosphorus, by those of Classes I, II, III^- and III^+, respectively. while a considerable amount of silicon, iron and manganese is absorbed by even the older roots. An example of those results is shown in fig. 3.

On the other hand, nutrient-uptake by excised roots was compared among the classified roots as well as longitudinal regions of a root. The results suggested that the order of nutriments in the degree of dependence upon younger roots for their uptake is as follows: NH_4-N>P>Fe, Si, Mn ; and K>Si. This trend sub-

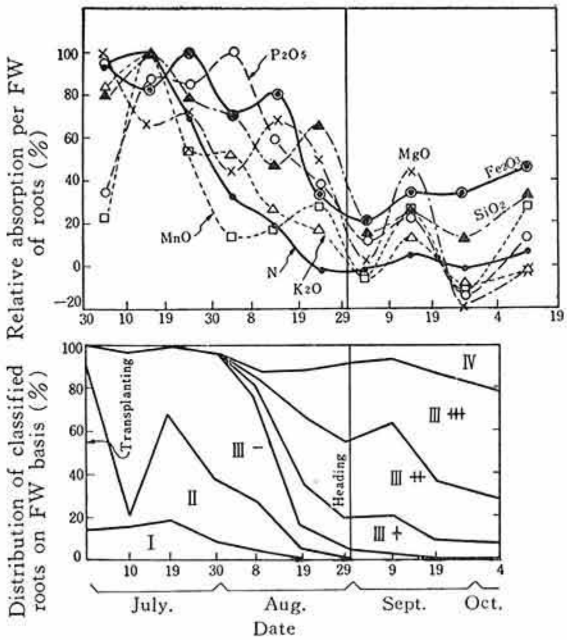

Fig. 3. Changes in the nutrient absorption per weight of roots and the distribution of classified roots according to the plant growth stage.

Symboles I, II・・・・IV indicate respective class of roots given in fig. 1, and −, +, ++ and +++ show none, little, moderate and much, respectively, in the degree of blackening on the root surface.

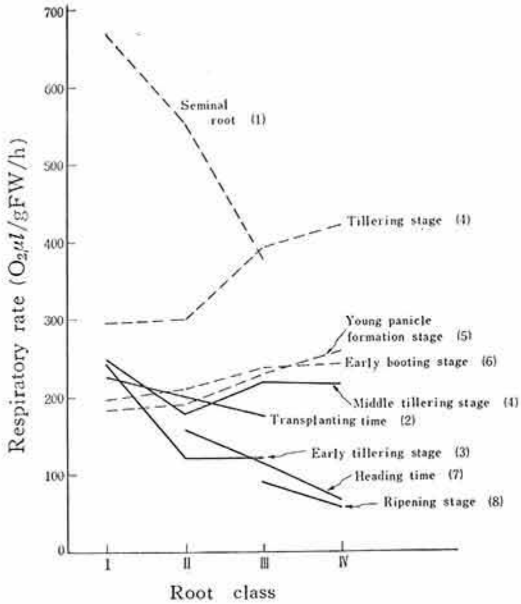

Fig. 4. Changes in the respiratory rate of classified roots according to the plant growth stage.

—— Soil culture - - - Solution culture

Numerals in brackets indicate progressive order of the plant growth stage.

stantially agrees with the result stated above. Therefore, it seems that the difference of absorption pattern among nutrients as the plants grow is related to the change in absorption characteristics connected with the age of roots.

Respiration of roots

The total respiration of roots per plant increases with the plant growth after transplanting and reaches a peak at about 20 days before heading, then decreases quickly. Respiratory rates of roots, both on fresh and dry weight basis, show the maxima at an early tillering stage, when the plant has the youngest roots in average age throughout the whole growth period, after that the rates decline as the plant growth progresses. These trends are similar to previously reported ones[6].

The respiratory rate of seminal root either in fresh weight or dry weight basis is highest at one day after germination, and then gradually decreases after germination. After transplanting, however, the relation between, the respiratory rate of a root and its age changes according to the growth stage of the plant. The respiratory rate of a root on fresh weight basis is in the order of I>II>III at an early tillering stage, and II>III>IV after heading, respectively, but it turns into the order of I>II<III, IV or I, II<III, IV during the period from tillering to booting stages as shown in fig. 4.

In longitudinal regions of a root, an active respiration is seen both at the tip and rootlet bearing parts. The respiratory rate at the tip surpasses that of other parts in young roots, but the rate goes down at the tip and rises up at the rootlet-bearing region, with aging of the root. This tendency is shown more clearly in the value per unit root length or on fresh weight basis than that on dry weight basis.

A high respiration in older roots, Classes III and IV, at the middle growth stage is attributable to the numerous active rootlets existing around the root surface.

Respiratory pathway of roots

The addition of organic acids of TCA (tricarboxylic acid) cycle such as malic, α-ketoglutaric, succinic, isocitric or fumaric acid promotes both the oxygen uptake and TTC (2, 3, 5-triphenyl tetrazoliumchloride) -reduction of the mitochondrial fraction of roots (Table 1). TTC reduction by roots is remarkably inhibited by monoiode acetic acid, an inhibitor of dehydrogenases, and there is a close correlation between TTC-reduction and respiration in excised roots in the presence of various inhibitors. These results may suggest that TCA cycle is functional in rice roots as an important intermediate pathway in the normal respiration.

Table 1. Effect on organic acids which participate in TCA cycle on oxygen uptake and TTC reduction of mitochondrial fraction of rice roots.

Substrate	Oxygen uptake		TTC reduction	
	μl/vess/h	%Increase	μg/tube/h	%Increase
None	27.1	0	3.67	0
Iso-citric acid	31.9	18	4.32	18
α-Ketoglutaric acid	57.6	112	6.74	84
Succinic acid	50.0	84	4.76	30
Fumaric acid	37.3	38	3.78	3
Malic acid	101.7	275	9.01	146

Mitochondrial fraction was prepared from the root of 7 days after emergence at maximum tiller number stage of the plant (var. Nōrin-29).

The respiration of excised roots is inhibited by KCN (potassium cyanide) and CO (carbon monoxide). The percentage of inhibition by KCN is generally high in young roots (Class I) but the decrease is not great even in older roots (Classes III and IV), and the inhibition is usually high both at the tip and basal part of a root. Rate of CO-sensitive respiration is also high in the tip and rootlet-bearing parts, and the aging of roots induces a decrease of the rate at the tip and an increase at the other parts.

The activity of cytochrome c oxidase in the homogenate and the mitochondrial fraction is generally high in young roots and it decreases with their aging, but a high activity is often observed in older roots.

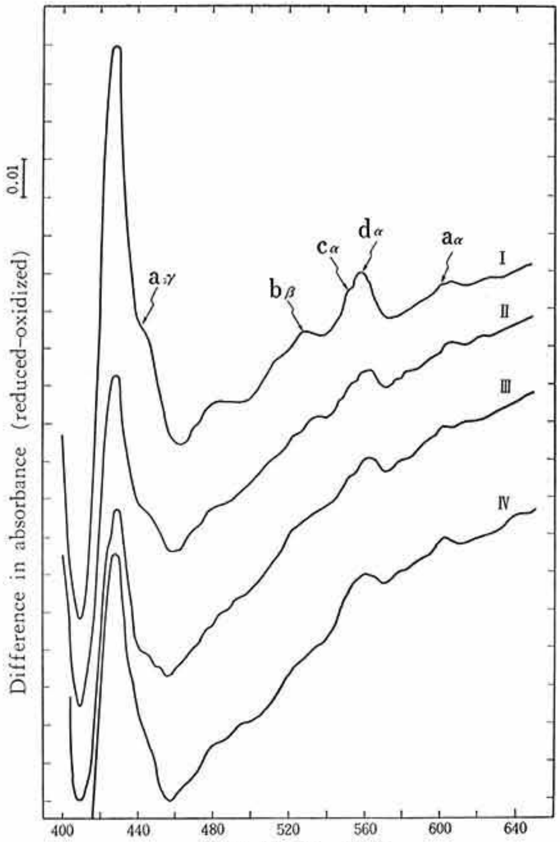

Fig. 5. Cytochrome components obtained by the difference spectrum of the mitochondrial suspension of classified roots at the early booting stage.

The mitochondrial fraction of roots contains various cytochrome components such as cyt. a_3 (cyt. c oxidase), a, c, b, etc., which are essential intermediates in the electron transfer system (fig. 5). The concentration of cyt. a_3, a and c per fresh weight of roots is generally in the order of I II III, IV during the stages from tillering to booting. Longitudinal distribntion of the cytochrome concentration shows a trend that cyt. a_3, a and c are concentrated at the tip and rootlet-bearing regions of a root.

These facts indicate that cytochrome-cytochrome c oxidase system does exist in rice roots together with TCA cycle, and this system is functional in the normal respiration *in vivo* as the most important electron transfer system.

Change in the respiratory pathway of roots with their aging

Cytochrome a_3 in roots probably controls the electron transferring velocity of cytochrome-cytochrome c oxidase system. because of its lowest concentration in the system. The ratio of cyt. a_3 concentration to respiration is always high in young roots (Class I) and gradually decreases with their aging, bnt it somewhat increases in older roots (Class III or IV) having a number of rootlets (fig. 6). This fact suggests that the ratio of respiration via cytochrome-cytochrome c oxidase system to total respiration is high in young roots and young parts of a root and it falls with their aging.

On the other hand, it is suggested that the respiration related with ascorbic acid oxidase is usually very low in young roots (Class I) and at the tip of a root, and it increases to a certain limit at a rapid pace with their increasing age, according to investigations both on the respiratory inhibition by sodium diethyldithiocarbamate and on the ascorbic acid oxidase activity of the homogenate. A similer result has been reported already[7].

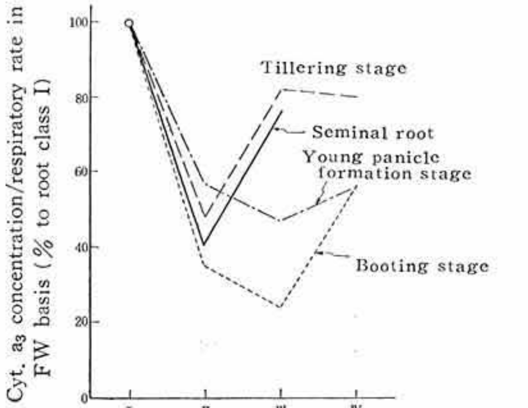

Fig. 6. Changes in the ratio of cytochrome a_3 concentration to respiratory rate of classified roots according to the plant growth stage.

Respiration through cytochrome system and the function of roots

photo-reversible inhibition by CO of nutrient absorption was tested using the intact roots of a rice plant at middle growth stage [3,4]. The rate of photo-reversible inhibition by CO to total absorption is K>Si>NH_4-N>H_2O, in the order, and the percent inhibition is about 70, 50, 25 and 0, respectively (fig. 7). This order coincides well with that of the inhibition of nutrient-absorption by hydrogen sulfide [1], sodium cyanide[5] etc., reported previously. Thus, it is concluded that the active absorption of nutrients is closely associated with the respiration of cytochrome c oxidase system, and that the essence of so-called aerobic respiration related to nutrient absorption is nothing but this respiratory system.

Moreover, it was found out that this respiratory system participates also in the emergence and elongation of roots.

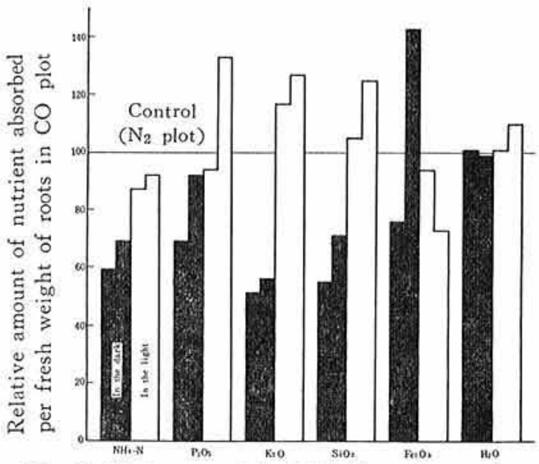

Fig. 7. Photo-reversible inhibition by carbon monoxide of the absorption of nutrients and water by attached roots.

For N_2 and CO plots, 95% N_2 gas + 5% O_2 gas and 95% CO gas + 5% O_2 gas, respectively, were bubbled into the culture solution. Values from two experiments are shown.

Conclusion

Young roots and young parts of a root hold a large quantity of water and potassi um, and they actively perform the respiration which contains active TCA cycle→cytochome-cytochrome c oxidase system, which may be coupled most effectively with oxidative phosphorylation. All of the active physiological functions of roots requiring energy, particularly active absorption of ions, will probably be dependent upon the activity of this respiratory pathway.

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 a 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 mainly in numerous, young rootlets bearing on older roots, which 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 to participate in the maintenance of such activity of roots and rootlets through the oxidizing action against the reduced soil condition.

References

1) Baba, I.: Nutritional studies on the occurrence of Helminthosporum leaf spot and "akiochi" of the rice plant. Bull. Nat. Inst. Agr. Sci., **D7**, 1-157, 1958 (in Japanese with English summary).
2) Baba, I. and K. Inada: Physiological studies on the root of crop plants. I. Some characteristics of rice roots clarsified as to their age in relation to nutrient-absorption. Proc. Crop Sci. Soc. Japan, **27**: 151-154, 1958. (in Japanese with English summary)
3) Inada, K.: Phyiological studies on the root of crop plants. II. Role of cytochrome exidase in respiration and nutrient absorption of rice plants. Proc. Crop Sci. Soc. Japan, **28**: 347-350, 1960.
4) Inada, K.: Physiological characteristics of rice roots, especially with the viewpoint of plant growth atage and root age. Bull. Nat. Inst. Agr. Sci., **D**:**6**, 19-156. 1967. (in Japanese with English summary)
5) Okuda, A. and E. Takahashi: Studies on the plant-physiological role of silicon for crop-plant (part 8). Some examinations on the specific behavior of lowland rice in silicon uptake. J. Sci. Soil and Manure, Japan, **33**: 217-221, 1962. (in Japanese)
6) Yamada, N.: Physiological basis of resistance of rice plant against overhead flooding. Bull. Nat. Inst. Agr. Sci., **D8**, 1-110, 1959. (in Japanese with English summary)
7) Yoshida, T. and J. Takahashi: Studies on the metabolism in roots of lowland rice (part 6). Respiratory and enzymatic gradient in rice root. J. Sci. Soil and Manure, Japan, **31**: 423-426, 1960. (in Japanese)

Identification of Seed Corn by Immuno-chemical Reaction Method

T. MACHIDA* AND S. SAKAGUCHI**

Chief,* and Researcher,** Kikyogahara Branch Station, Nagano Prefecture Agricultural Experiment Station.

Recent developments in livestock industry have increased demands for corn so rapidly that needs for breeding improved variety and producing quality seeds of corn are now a matter of urgent concern.

In recent years corn is mostly bred as F_1