6. EFFECT OF WATER MANAGEMENT ON PADDY SOIL METABOLISM AND ITS USE IN THE GROWTH CONTROL OF RICE PLANTS

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From the viewpoint in the field of soil and fertilizer, the effect of water management on rice production may be considered in two ways.

One of them is to keep soils, i.e. the environment of roots, in good condition, and the other is to control the supply of nutrient, especially of nitrogen and furthermore to make active control of the growth of rice plants by limiting water supply.

The metabolism of the microbes in submerged soil and its effect on root rot and abnormal growth of plants will be described. The effect of countermeasures such as controlling water management will also be clarified and some methods which determine the degree of the necessity of water management will be discussed. The effect of restriction of soil moisture content on the control of the excessive growth of rice plants in warm regions will be described, too.

1. Metabolism in submerged soil

Oxydative condition of paddy fields changes to oxygenless reductive condition by submergence because of positive shut out of air penetration. (Fig. 1) The majority of microbial flora, therefore, change from aerobic microbes to facultative anaerobic microbes and furthermore changes to obligative anaerobic ones.

The metabolism under oxydative condition is mainly oxydative decomposition owing to the respiration of microbes, while that under reductive condition is almost anerobic decomposition because of the fermentation of microbes. In the oxydative decomposition of easily decomposable organic matter, the final decomposition product of contained carbon is CO_2 and that of nitrogen is NO_3. Therefore, the existence of accumulated intermediate products does not presist for a long while. In the anaerobic decomposition, intermediate products such as organic acids and alcohols and various substances produced from the intermediate products as the substrate are accumulated in the soil, hydrogen sulphide and other sulphides increase by the reduction of sulphates, and easily soluble reduced types of metals such as iron and manganese augment. Some of these substances are injurious to rice plants, therefore, how to control them is an important problem for rice culture.

After the flooding of paddy fields, the metabolism progresses rapidly according to the development of the reduction caused by water soluble and easily decomposable organic matters as the substrate.

Although organic acids such as acetic acid and butyric acid are produced abundantly in the beginning of the metabolism, the production of these organic acids remarkably declines according to the decrease of easily decomposable organic matter in less than one month in ordinary soils.

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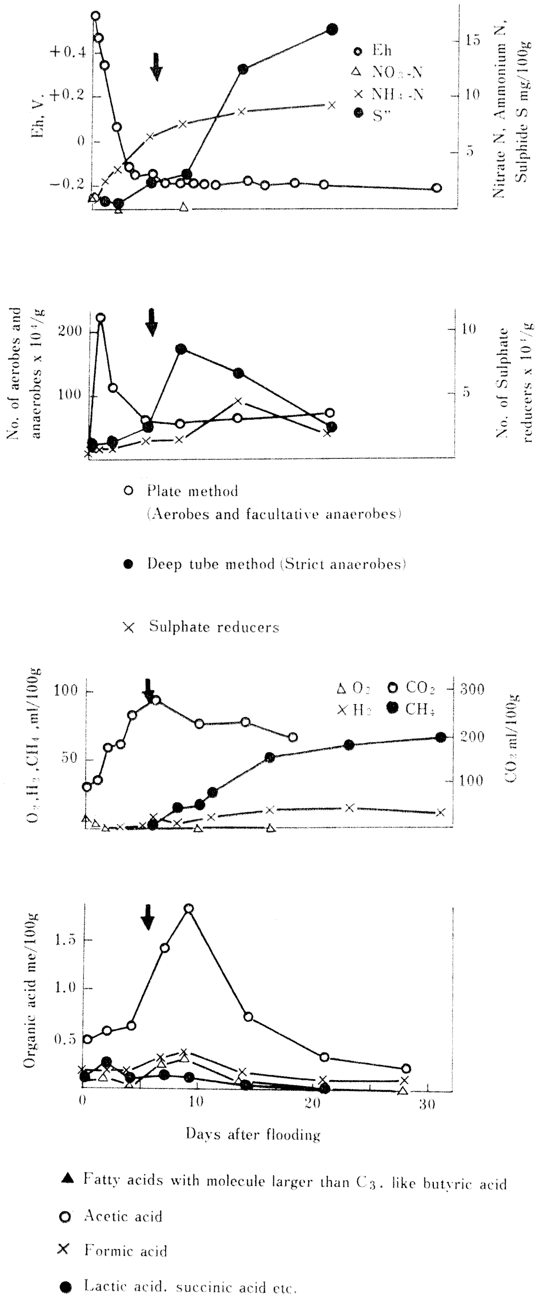


Fig. 1. Microbial activities in flooded soil kept in the syringe (Air-dried paddy soil sampled in Hekinan City, Aichi Prefecture was incubated at 35°C; the arrow separates the first and second steps.) (N. Takai et al, 1955–7)

2. Influence of metabolism on rice plants and control of rice plant's damage by water management

As in the case of ill-drained paddy fields, in the paddy field in which easily decomposable organic matter is accumulated, water permeability is not good and rice plants suffer the decline of nutritional growth from root damage and absorption hindrance of nutrient, and even with the plants of well-grown appearance, the maturity becomes poor and the yield decreases.

Despite the permeability in some degree, plowing-in of fresh organic materials such as stubbles of Italian ryegrass, Chinese milk vetch and rice straw before flooding and abundant application of livestock excreta cause abnormal reduction in paddy fields, and decomposition products caused by microbes may exert baneful influence upon the growth of rice plants.

Although there are many kinds of injurious substances which may cumulatively increase damage in cooperation with other growth hindering factors such as strong soil reduction, low pH, low content of active iron, nutrient deficiency etc., only the injurious substances by which rice plants evidently suffer from damage during the growth stage will be discussed hereunder.

The rice plant suffered from damage during its vegetative growth stage can recover by itself because of the compensating ability caused by the development of new roots.

Since the cropping season, however, is limited in Japan, the rice culture with the variety selected for the proper cultivation season often results in decreased yield which is due to the retarded growth caused by injury in the early stage.

On the other hand, the damage given to the roots of rice plants in the later stage of growth is evidently reflected on the maturity of rice.

In the reproductive stage of the plants, the development of new roots is hardly recognized but only the development of dichotomous root is accompanied with the growth of rice plants.

There are many factors which give bad effect upon the maturity of rice, including bad weather, inferior growth pattern, poor root development etc. Injurious substances in the soil may also badly influence on the maturity. The study on this problem is not yet advanced. But some examples of the studies on sterility of flowers can be found as will be described later, because sterility is a very specific phenomenon.

1) Injurious substances produced in the early stage of growth

In water culture, ferrous iron greatly hinders the absorption ability of rice plants to K and SiO_2 and results in a great decrease of fine grain weight (Baba, Tajima 1960).

Ferrous iron in soil, as in the report on the muck paddy field by Takagi (1958), reached 500 ppm in midsummer with the application of straw as manure and resulted in poor development of the root system. But it scarcely rendered influence on the yield, and as a result, it did not usually cause any serious trouble. But in the case of the soil of strong acidity or of poor potassium, the hindrance by excessive ferrous iron may be found as seen in 'AKIGARE' (Kurosawa et al. 1965, Takahashi 1970).

The majority of lower fatty acid is exclusively of acetic acid as shown in Fig. 1, and it is of trifling trouble in usual paddy fields. But in sandy or peaty autumn-declined soil, acetic acid and butyric acid often increase up to hindering extent.

In peat soil, these acids decrease once and increase again showing a peak between those of ferrous iron and sulphides, and then decrease suddenly. Therefore, there is always injuring possibility by these acids to the root system throughout the period from the beginning of flooding to midsummer (Takijima, 1963).

As to the injury caused by sulphides, Mitsui et al. (1951) reported that an evident injury on nutrient absorption was revealed at 0.07 ppm of hydrogen sulphide in a long-run water culture. In general, younger roots suffer greater respiration hindrance from hydrogen sulphide, and the growth phase plants fall into disorder and the translocation of metabolic products is restrained (Okajima et al. 1953). Suzuki et al. (1954), however, reported that 2 to 3 ppm hydrogen sulphide scarcely shows bad influence upon the paddy yield in ordinary soils.

Carbon dioxide has also much influence upon the physiological function of the root system of rice plants. The hindrance by CO_2 becomes greater especially in the soil of acidic reaction (Tanaka et al., 1967).

These injurious substances are produced one after the other at the time of soil reduction after the flooding of paddy fields, and the plants suffer combined effects from these substances.

The appearance of temporary injuries and the recovery from them are different by the nutrient supply in paddy fields and the growth condition of rice plants.

As the necessary water management against these injuries, in the soil of good permeability, the pipe of underdrainage is fully opened to increase water permeability and to make exchange of used water for new one. In the case of poor permeability, the water is irrigated deeply and then drained after some hours as socalled flashing treatment. It is usually practiced in salt-accumulated soils. This method is desired to be repeated if possible. In such less-permeable soil, the excessive moisture cannot easily be eliminated by surface drainage alone. As a result, fermentation does not cease, soil temperature becomes high owing to the direct solar radiation and lack of water. Consequently, much injurious substances may be produced sometimes.

As to these injurious cases, it is improper to consider that rice plants are merely suffering from nitrogen starvation. The nutrient absorption is hindered by injurious substances. It is, therefore, necessary to proomte absorption of nutrient making higher concentration of the ammonium in soil solution and to increase the resistibility of roots and finally to recover the declined growth of plants. Therefore, increased application of nitrogen becomes necessary. Nitrogen shortage makes rice plants less resistible and causes root damage (Okajima, 1958).

The experimental results obtained by the Hiroshima Agricultural Experiment Station showed that the effect of increased application of nitrogen was conspicuously high in the first year of the application of fresh rice straw (Fig. 2). In the second year,

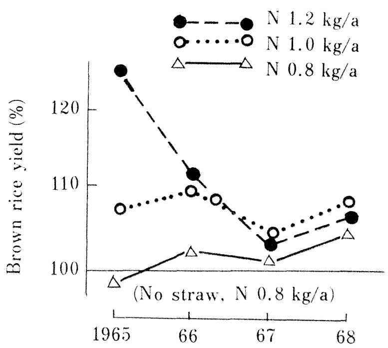


Fig. 2. Changes in the effect of nitrogen application on rice yield in straw-applied paddy field (wheat straw 60 kg/a in spring, rice straw 100 kg/a in autumn)
(Hiroshima Agr. Exp. Stat.)

however, the effect declined, and it was hardly recognized in the third year.

These phenomena may be caused by the adaptation of microbial flora related to the decomposition in soil because it has been recognized that, in the first year of the application of fresh rice straw, paddy fields show boiling-like appearance by the temporary active gas-fermentation after the flooding, but this boiling declines year by year probably due to the vigorous growth of methane bacteria.

2) Injurious substances produced in the later stage of growth

In the early stage of growth, the decomposed metabolites of the organic matter applied to paddy fields before the flooding are mainly derived from the decomposition of the easily decomposable organic matter such as sugars to the extent of hemicellulose, and the metabolism by microbes becomes active for a while.

The growth hindrance by injurious substances, however, is yet remained afterward. Different injurious substances are naturally produced by the decomposition of cellulose as a main source. Furthermore, rice's root itself becomes the substrate of injurious substances. Since the development of new roots mostly ceases after the maximum tiller number stage, existing activities of roots must be kept at high level throughout the stage of reproductive growth. This is an especially important point for the maturity of rice, and a problem comes out on this point. It is the development of ineffective tillers.

Since each root of rice plants comes out from corresponding individual tiller, the death of a tiller result in the death of its corresponding roots. Dead roots are naturally decomposed by microbes and render unfavorable influence upon the reduction of root system.

Above all, abundant application of fertilizers makes nutritional growth of plants exceed and makes many ineffective tillers come out. As the result, the oxidation-reduction condition of root system becomes worse, and rapid increase of ferrous iron and development of hydrogen sulphide are accelerated to be the cause of root-rot.

There is a close relation of cause and effect between the production of hydrogen sulphide and the outbreak of root-rot, and hydrogen sulphide seems to be produced by sulphate reducing bacteria derived from dead roots as the substrate. In degraded paddy fields, hydrogen sulphide may be produced even after the heading stage.

Copiously produced ferrous iron and hydrogen sulphide decline root activity and hinder nutrient absorption.

It is well-known that hydrogen sulphide penetrates into plant body and has influence on the growth of rice plants in later stage disturbing the metabolism of plants.

Although the countermeasure such as heavy application of iron-rich substances against the injury caused by hydrogen sulphide must be practiced, the cause of the abnormal growth of rice plants in the later stage, especially that of sterility of flowers, is another thing.

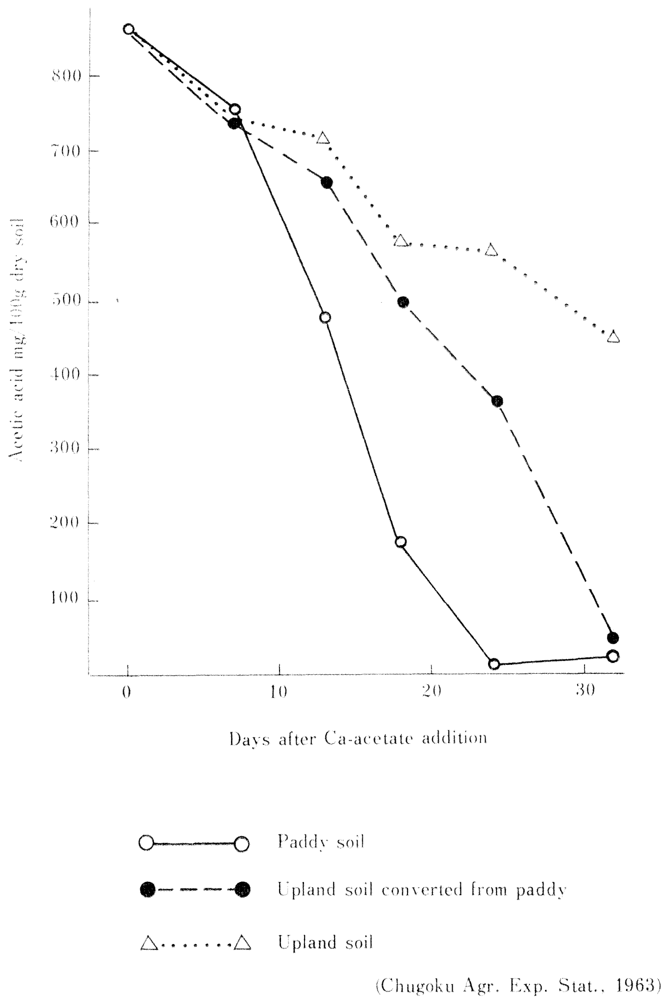
3) Abnormal growth of rice plants in the later stage

Abnormal growth of rice plants, including severe sterility, is often found on the paddy fields in the early stage after the conversion from upland fields and on the subsoil exposed by the large-scale land readjustment (Inoue et al., 1953; Kitamura et al., 1955). This phenomenon is also found widely in the rice cropping regions of America, Australia and other Western countries where it is known by the name of "Straight head" as an abnormal growth of which cause is yet obscure. Various types of this phenomenon appear according to the difference of soil from the Loam to the Clay, and in many cases, the appearance of such varied types can be recognized repeatedly for two or three years.

The outbreak of abnormal growth was s apparently decreased by non-nitrogen and non-compost cultivation, soil-dressing with the soil of normal paddy fields and application of lime. The abnormal growth did not appear at the temperature below 25°C. In the paddy fields made by the conversion of upland fields in which lime was applied repeatedly during the seasons of summer and winter cropping, the growth of rice plants was normal, but simple cropping and repeated application of composts of poor quality increased the outbreak of abnormal growth.

Shiga et al. (1961) recognized that the application of rice straw just before flooding time increased sterility more than the application of composts.

Sakai and Ooyama (1965) made some experiments to clarify the mechanism of abnormal growth. They made a pot culture test, at first, adding glucose to the soil during the period from young panicle formation stage to heading time. The soil boiled and and smelled of butyric acid, and the leaves of rice plants curled up in the daytime, nevertheless sterile grain did not increase so much. Therefore, they concluded that the



(Chugoku Agr. Exp. Stat., 1963)

Fig. 3. Decomposition process of acetic acid in soils under anaerobic condition

Table 1. Effect of addition of Calcium acetate on the occurrence of straighthead of rice plants (H. Sakai and N. Ohyama, 1965)

Calcium acetate	Amount of cellulose	Panicles (g/pot)	Straw (g/pot)	Panicle weight (g)	Spikelets/ panicle	Sterile grain/ panicle	Sterility (%)	Gas formation ml/100 g soil
(0.05%)	(%)							
Not added	0	29.0	121.5	0.51	59.8	46.6	78	tr
	0.2	3.9	76.5	0.15	21.9	21.9	100	0.5
	0.4	1.7	67.0	0.07	8.2	8.2	100	tr
Added	0	65.8	92.5	1.15	62.8	7.5	11.9	44.2
	0.2	57.6	54.5	1.44	70.1	16.2	23.2	37.2
	0.4	38.2	37.5	1.23	60.1	13.8	23.0	35.2

Diluvial soil of pH 6.8 was used in $\frac{a}{2000}$ pot; gas formation was measured by syringe method with 0.1% Calcium acetate solution at young panicle formation stage.

abnormal growth cannot be caused merely by the decline of Eh, increase of ferrous iron and production of organic acids.

And then, they found that the soil which causes abnormal growth has little potentiability to gasify acetic acid under anaerobic condition at least until the young panicle formation stage (Fig. 3), the addition of cellulose aggravate the abnormal growth and some injurious substance is related to this aggravation, and the production of this unknown injurious substance becomes very active about 30 days after the addition of cellulose to submerged soil.

On the basis of these results, acetate and glucose were added to the soil immediately after flooding to strentghen the soil potentiality for the decomposition of acetic acid. As a result, no sterility was recognized in spite of abundant application of cellulose. (Table 1)

It is, therefore, considered that the mechanism of the appearance of abnormal growth may be due to some injurious substance produced with cellulose as a substratum under flooding condition of such soil, and that if the activity of methane forming microbe in the soil is kept as high as in the soil of normal paddy fields, the injurious substance and its substratum organic acid, will be decomposed and eliminated, and therefore, no abnormal growth will be caused.

The application of lime may promote the decomposition of organic matter and result in the decrease of cellulosic substances in the soil, and furthermore, the activity of methane forming microbes will be raised effectively because the soil is kept in alkali side.

In their study on injurious substances, Inoue et al. (1955) reported that methyl mercaptane produced quite similar abnormal growth.

If rice plants are cultured in high ridge or sufficient drainage treatment is conducted about for ten days before the young panicle formation stage to promote the oxidation of soil, the growth of panicles and ripening become normal and, therefore, the injury can be prevented. (Table 2) Midseason drainage is now a common practice in Japanese rice culture, so severe sterility might not occur in these days. It is uncertain whether this kind of sterility may be involved or not, in the case of ordinary reproductive growth in which small numbers of sterile grains are often found.

3. Inference on the necessity of water management

The control of injurious soil condition by which rice plants are affected is possible

Table 2. Relationship between time and duration of drainage and occurrence of abnormal growth of rice plants
(E. Kitamura et al., 1955)

Treatment of drainage	Heading time	No. of normal tillers/hill	Headed tiller		Unheaded tiller		No. of abnormal tillers/hill		Average No. of spikelet/panicle	Fertility
			Perfect	Imperfect	With flag leaf	Without flag leaf	Late developed	With branch tiller		
(Drained period)	(Date)		(%)	(%)	(%)	(%)				(%)
A. Continuous flood	—	28.0	0	0	45.0	55.0	11.7	0.7	0	0
B. July 31—Aug. 10	Sept. 11	27.0	95.6	4.4	0	0	0	0	69.9	94.8
C. 〃 21— 〃 〃	〃 10	26.0	97.3	2.7	0	0	0	0	64.1	94.2
D. 〃 12— 〃 〃	〃 8	19.7	97.5	2.5	0	0	0	0	76.5	93.5
E. 〃 21—July 31	〃 9	23.3	98.7	1.3	0	0	0	0	67.1	90.6
F. 〃 12— 〃 〃	〃 8	19.8	100	0	0	0	0	0	74.7	92.4

Table 3. Effect of percolation on the utility of applied manure (N. Ohyama and H. Sakai, 1968)

Percolation treatment	Weight of straw (g)	Weight of paddy (g)	Fertility (%)	Loss of nitrogen with percolation (mg/pot)	Fe^{++} (mg/100 g dry soil)		Gas formation from acetic acid (ml/100 g dry soil)	Root development test of young seedlings	
					Aug. 10	Aug. 15		Aug. 9	Aug. 15
Treated	59.7	45.9	91.0	0	104	119	142.2	8.6	9.0
Non-treated	69.1	53.6	96.5	603	242	129	7.6	8.3	8.1

Note: 1. 800 g well-decomposed manure per $\frac{1}{2000}$ are pot with no fertilizer.

2. Percolation treatment: approx. ℓ/day.

by water management as described above. Hereunder, description shall be made how to infer the necessity of water management in the case in which not only the maintenance of good growth and yield by preventing the outbreak of injury but also an active increase of yield by means of application of manures and chemical fertilizers are desired.

Although water management is necessary without discussion when an injurious growth appeares, it is very difficult to decide whether water management is necessary or not in the case of no appearance of any injury including excessive vegetative growth, because the loss of nitrogen is always accompanied with water management as described by Onikura.

Therefore, the necessity of water management cannot be easily decided only by the appearance of produced ferrous iron or decline of Eh value.

Water permeation results in the decline of Eh value and the increase of ferrous iron in some kind of soil as reported by Takai et al. (1970). In such soil, the activity of microbes is decreased and the decomposition of organic matter is checked by the accumulation of metabolites. Water permeation can eliminate accumulated metabolites and promotes ammonium production by accelerated decomposition of organic matter. This is the cause which makes rice plants grow well in spite of declined Eh value and increased ferrous iron. It is the same about the case of abundant application of compost (Table 3).

1) Soil diagnosis

The comparison of reductive condition of soils between root zone and interrow space is a way of soil diagnosis. An example on ferrous iron is shown in Fig. 4. As this is an example from a dry and direct sowing paddy field, though the production of ferrous iron increases according to the progress of plant growth, the soil of root zone is more active in oxidation and less contained with ferrous iron because of the high oxidation potential of healthy roots. On the contrary, in the stage before heading, the soil of root zone reversely turns into more reductive condition. This evidence reveals the existence of root-rot. Accordingly, the occurrence of root-rot can be found as early as possible by the difference of reduction activity between the soils of root zone and interrow space (the contrast) and by the time of the increase of reduction activity in the root zone soil, and these factors may be used to determine the time when to begin the water management.

The reduction activity of soil can also be determined by the change of Eh value

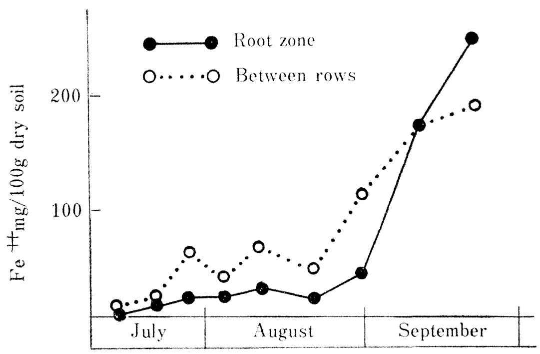


Fig. 4. Amounts of ferrous iron in paddy soil in upland direct sowing (Chugoku Agr. Exp. Stat., 1963)

measured continuously with the platinum electrodes put into the soils of root zone and interrow space during the cultivation period.

The platinum electrode, however, is limited in number to be used at one time and in a very narrow space to measure the Eh value.

Therefore, the method invented by Yamanaka et al. (1957) to measure ferrous iron seems more appropriate and favorable for this purpose.

Furthermore, the occurrence of root-rot may be foreseen by the concentration of injurious substances of minute existence as mentioned above. This method, if it is possible to restrict the products derived from root-rot, will be very useful. The research on this point is not yet advanced. Takijima (1962) proposed a simple method to presume injurious condition by the examination of the growth (principally root elongation) of the young plants planted in soil or steeped in drained water.

2) Root diagnosis

Another kind of method is the direct examination of root activity. There are two methods of this kind. One is to determine the activity of dug out roots by means of the measurement of α-Naphthylamine oxidation potential. Another is the direct examination of the roots of rice plants left as they are in the soil of fields. This latter method was invented by Nishigaki et al. (1959). In this method, radioactive phosphorus (^{32}P) is injected into the root zone in the soil. The radioactive element is then absorbed by roots and transported up to the aerial part of plants. The amount of ^{32}P thus transported is counted by time.

To measure the amount of liquid exuded for a certain time from the stalk cut at its lower end is also one method though its accuracy is not so high.

Table 5 shows the activity of roots of tropical rice plants as an example of the

Table 4. Growth status of rice seedlings in flooded soils previously air-dried
(Y. Takijima, 1963)

Soil	Dry soil used	Eh of soil		Length of top	Length of root	Relative Percentage	Fresh weight per 5 plants		
		Initial	Final				Top	Root	Total
	g	mv	mv	cm	cm	%	g	g	g
Arakawa	289	+520	+296	19. 7	12. 1	100	0. 44	0. 20	0. 64
Chiba	293	+308	+ 95	18. 7	9. 3	77	0. 46	0. 17	0. 63
Nagano	268	+557	+118	20. 5	10. 3	85	0. 50	0. 23	0. 73
Iwanuma (muck)	237	+264	+ 24	17. 0	7. 8	65	0. 44	0. 13	0. 57
Tochigi	176	+366	+144	19. 6	11. 1	92	0. 48	0. 19	0. 67
Iwanuma (peat)	143	+310	− 20	20. 5	8. 5	70	0. 48	0. 19	0. 67

Remarks: Soil cultures were conducted from 2 to 11 days after flooding.

Table 5. Effect of season and growth stage on rice root activity
(All India Co-ordinated Rice Improvement Project, 1971)

(μg α-Naphthyamine/g/hr)

Season	Booting	Heading	20 days after heading	Harvest
Rabi (21–42℃)*	68. 4	53. 4	47. 5	24. 5
Kharif (14–32℃)*	24	18	15	5

* Recorded during maturity period.

measurement of α-Naphthylamine oxidation at every growth stage. This is a very interesting result because root activity was very high even after the heading time when rice plants came into maturity under high temperature as in dry season, and this high activity was still maintained even at the time of harvesting. Therefore, Japanese theory that root-rot is promoted by the higher temperature in warm regions may be denied by this result.

On the contrary, in the monsoon season, root activity declined remarkably for the first time according to the fall of temperature after the heading time in spite of fine weather during maturing period, and the progress of root rot was apparently accelerated by low temperature.

It must be remembered, however, that this result was obtained from alkali soils.

3) Mn/Fe ratio in rice plants

The ratio of Mn/Fe in leaves or straw can be used as an index to clarify the cause of poor maturity even after the yield investigation.

Although the nutritional physiological basis of Mn/Fe ratio is not always so firm, in general, Mn is absorbed mainly by healthy roots while Fe is apt to be absorbed by damaged roots. Consequently, a high value of Mn/Fe ratio means healthy roots, while a low value means damaged roots. This ratio is naturally variable by the difference of soils. Especially in the soil of abundant easy soluble Mn, strict comparison is impossible because large amount of Mn can be absorbed. But the comparison between similar soils may be possible and, therefore, this Mn/Fe ratio can be used as a related value for the determination of root activity.

Table 6 shows an example of the Mn/Fe ratio of high yielded rice plants. The Mn/Fe ratios of high yielded rice plants are higher than that of ordinary plants, which is about 1.0, and some of them are more than 10. In this table, the value obtained by the Central Agricultural Experiment Station is comparatively low. This low value was obtained from the paddy field in which a huge amount of compost was applied.

Table 7 shows the relation between Mn/Fe ratio and water management. It is distinctly recognized that root damage appeared in the paddy field flooded always and the value of Mn/Fe ratio was less than 1, while, in the paddy field where midseason drainage was carried out in early stage and root activity was kept at high level, the

Table 6. Mn/Fe ratio of high yielded rice plants (Chugoku Nat. Agr. Expt. Stat. 1971)

Materials collected from	Chugoku Nat. Agr. Expt. Stat.	Mr. Taniguchi	Cent. Agr. Expt. Stat.		Mr. Kudo		Mr. Tan		Mr. Kitahara
Year	1967	1967	1958	1959	1960	1961	1960	1961	1960
Yield (kg/a)	82.6	89.7	80.6	80.2	105.2	63.3	94.3	75.8	71.7
Mn/Fe	11.7	12.8	3.8*	2.3*	6.2	10.7°	2.6	7.3*	4.7

* Leaf blade, others are stem and leaf.

Table 7. Relation between Mn/Fe ratio of rice plants and water management (Chugoku Nat. Agr. Exp. Stat. 1971)

Treatment	June 17	July 1	July 13	July 26	Aut. 18	Oct. 5
Early drainage*	1.05	1.21	1.78	2.12	1.93	2.28
Flooding	1.05	0.51	0.75	0.78	0.40	0.78

* June 20 to July 12.

value of Mn/Fe ratio increased apparently.

4. Growth control of rice plants by water management

It is an important problem in fertile soil as well as in heavy fertilizer application as in Japan.

The growth of rice plants is greatly influenced by the way of nitrogen supply. The methods of water management such as midsummer drainage, intermittent irrigation and cold water irrigation was intended to control the growth of rice plants by making the runoff or denitrification of excessive nitrogen and limiting the discharge of soil nitrogen. Soil moisture is usually kept at 80 percent level of the maximum water holding capacity for this purpose.

The limited supply of nitrogen by such methods, however, may be effective to a certain extent in the soil fertilized with continuous application of abundant composts in warm regions, but it may not be effective to control excessive nutritional growth of plants. It was believed by this cause that a high yield cannot be obtained from the rice culture in warm regions except the case of cultivation with short-culmed varieties.

The late irrigation method was once considered as a countermeasure against the autumn-decline of rice culture in warm regions. In this method, the surface water of paddy fields is completely drained after the taking root of seedlings, and the field are kept in uplandlike condition until the young panicle formation stage and then flooded again. As a result, this method obliges rice plants to be in the growth pattern of autumn-vigor.

In this method, the uplandlike condition in the field is very effective to limit water supply as well as nitrogen supply. The rice plants come into the growth pattern of autumn-vigor by this method, nevertheless the yield does not increase so much because of the less number of panicles.

Sakai and Kawamoto (1968) adopted, then, the eariy drainage cultivation. In this method, tillering is fully advanced until the determination stage of productive panicle's number (the stage when the tiller number which corresponds to the necessary panicle number predetermined in response to the desired amount of yield) was obtained and then surface water is drained to keep fields in uplandlike condition for about one month until the young panicle formation stage. This method as well as the late irrigation method strictly limits the nutritional growth of plants for a while.

As the result of this cultivation, though the yellowing of leaf apexes and burning up of lower leaves appear, the root damage caused by the declined concentration of nitrogen contained in plants does not occur because of the uplandlike condition, and lodging also does not appear so much because of shortened lower internode. As it is shown in Table 8, limited water supply results in the decrease of protein synthesis and increase of carbohydrate metabolism in rice plants. Consequently, dichotomous rooting progresses, late stage growth turns active, ripening becomes good and a high yield is expectable owing to reflooding as well as additional manure.

Drainage facilities must be completed to practice water management at any time when it is needed for the growth of rice plants. Only the accomplishment of such facilities makes it possible to bring high yielding rice culture with abundant application of composts and fertilizers.

Since water management, however, makes the eluviation and denitrification of soil nitrogen as reported by Onikura, the water management on less fertilized fields may result in a decreased yield. It is uncertain whether Japanese method of water management is immediately applicable or not to the paddy fields of South East Asian countries where the amount of applied fertilizers is less than that in Japan. It also must be

Table 8. Effect of water management on the growth of rice plants —Total carbohydrate in stalk and leaf sheath

(Chugoku Nat. Agr. Expt. Stat. 1965)

(glucose %)

	Treatment	June 17	July 2	July 19	Oct. 11
N abundant	Flooding	26. 0	29. 5	39. 7	37. 9
	Optimum moisture	—	32. 2	47. 0	39. 1
	Flooding after optimum moisture	—	—	—	38. 0
	Optimum moisture after drying	—	35. 4	48. 7	36. 4
	Flooding after drying	—	—	—	37. 9
	Plot to plot flow	—	35. 0	41. 0	34. 0
Medium	Flooding	27. 0	36. 9	44. 2	37. 5
	Optimum moisture	—	38. 2	48. 5	37. 0
	Flooding after optimum moisture	—	—	—	38. 0
	Optimum moisture after drying	—	38. 7	54. 5	34. 0
	Flooding after drying	—	—	—	35. 5

Transplantation: May 29, Surface drainage: June 16, Reirrigation: July 20, Opt. Moist.: pF 1. 5–2. 2, Drying: pF 3. 1–3. 7.

kept in mind that tropical rice varieties have very high root activity at high temperature.

It is difficult to improve poor soil conditions and to secure a reasonable yield from paddy cropping only by the practice of water management. Lime, phosphate and potash must be applied at least for the improvement of sulphated acid soil and potassium deficient soil.

Rice plants are easily affected by inferior soil condition when the amount of applied nitrogen is not sufficient. Since high temperature accelerates the growth of rice plants, the plowing-in of crop residues should be performed about one month before the commencement of rice culture in the regions of high temperature. It eliminates negative factors and promotes positive factors such as the supply of fertilizer components.

Straighthead often appears strikingly when upland fields are converted into paddy fields. In those fields soils, particular injurious substances are likely to accumulate at the reproductive growth stage. The midseason drainage (Nakaboshi in Japanese, it means the surface drainage practiced in mid course of the flooding stage), therefore, should be practiced sufficiently before the young panicle formation stage which is critical stage for the outbreak of sterility of flowers.

Question and Answer

S. Okabe, Japan: Figure 2 shows changes in the effect of nitrogen application on rice yield in straw-applied field. Does the figure present any significant difference of yields due to the different levels of nitrogen dosage in the later years after straw application?

Answer: I am not sure whether they analyzed the yield data statistically. However, the trend of necessary nitrogen addition has clearly changed year by year. It happens due to adaptive growth of methane bacteria. In the first year injurious substances especially organic acids once accumulate to give some damage to rice plants before the timely removal by methane bacteria. Additional nitrogen application is quite necessary to make nitdogen-starved plants more resistible. Once methane bacteria became active enough, produced injurious substances are smoothly converted into unharmful methane gas by the corresponding bacteria later on.