INORGANIC NUTRITION FERTILISATION and SOIL AMELIORATION for Lowland Rice

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by

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PLATE. Degraded paddy soil

(By courtesy of K. KORO)

(1) Bleached layer (2) Accumulation layer

Preface

In summer 1952 the Food and Agriculture Organisation of the United Nations scheduled an International Training Center on Fertiliser and Soil Fertility for Rice at the Agricultural College in Coimbatore, South India. As one of the main lecturers I had the opportunity to deliver lectures on the Inorganic Nutrition, Fertilisation and Soil Amendment for Lowland Rice, principally based on the recent researches and experimental works done in Japan. The unexpected response of the trainees assembled there encouraged me to publish a revised and supplemented English text for a wider audience.

During the past twenty years the chief effort of the plant nutritionists and soil scientists in Japan has been focused on the particular behaviour of the lowland rice as contrasted to the upland crops, and of the waterlogged soil as contrasted to the upland soil.

Unfortunately, however, these works have mostly been published in Japanese incomprehensible to foreigners.

Obviously, this small volume cannot have any of the characteristics of a handbook. Most of the illustrative materials except for introductory or referred illustrations are drawn from the materials with which the author has had the direct or indirect contacts. Despite the preclusion of a number of important contributions, they are sufficient, I believe, to present a general perspective of several important characteristics of the rice cultivation in Japan from the soil and plant scientific view.

It is urgently hoped that the lines of consideration presented in this booklet will encourage further researches and extension works widely in abroad of diverse climatic and soil conditions.

I wish to express my deep appreciation to K. Tensho and K. Kumazawa for their assistance in typewriting the manuscript. I am also greatly indebted to Prof. Dr. M. Shioiri for allowing me whatever facilities I needed.

The author

Tokyo
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Introduction

In contrast to the upland crops, lowland rice is particular in that it develops its root system deep in the soil extremely deficient in oxygen. Under waterlogged condition the arable soil loses oxygen, primarily because of the oxygen consumption by decomposing organic matter under limited oxygen supply from the surface water. Nevertheless it can take up water and various nutrient elements necessary for its growth, as well as the upland crops do from the upland soil. Owing to the particular ability to supply oxygen by itself the root of rice plant can respire, take up nutrient elements and grow.

Moreover, the predominating situation in the waterlogged soil is distinctly peculiar as compared to the ordinary arable soil. Reduction prevails except for a portion of the soil existing in the uppermost surface. Matters receive reduction both biologically and chemically. This will naturally result in a different type of plant food supply as compared to the upland.

For considerably high soil fertility level in the waterlogged soil are responsible, on one hand, the accumulative effect of reserved organic matter under minimised oxygen supply of waterlogged soil, and on the other hand the nutrients supply by irrigation water. The main available form of nitrogen in the flooded soil is ammonia as against to the both forms, i.e. ammonia and nitrate, in the upland soil, although rice plant can utilise both under suitable waterculture condition. Sulphate added in the form of chemical fertilisers will soon be converted into sulfide, which is surprisingly toxic to the nutrients uptake by crop plants, if it exists in soluble or free state.

The cultivation of lowland rice cannot be comprehended on the basis of the knowledge accumulated from the upland crops and upland soils. The particular relationship among the waterlogged soil, fertiliser application and the growth of lowland rice will be illustrated in the following lectures.

CONTENTS

Part I. Inorganic Nutrition of Lowland Rice

1. General concept of ion uptake

The older plant scientists tried to interpret the mysterious phenomenon of the uptake of nutrients by plants, primarily on the basis of physicochemical terms, such as ion diffusion, osmotic pressure and permeability of cell membranes. But, as knowledge was accumulated, particularly on the *selective accumulation* of plant nutrients, in other words, diffusion against concentration gradients, the simple physicochemical explanation has become extremely insufficient.

In this connection, I should like to refer to the interesting work of HOAGLAND,[1] a well-known plant nutritionist in California.

During the First World War he occasionally became engaged in a comprehensive investigation of the giant kelps of the Pacific Coast, with the intention of gaining knowledge that would be helpful in recovering the then much needed potash present in the kelps. He, was impressed by the remarkable selective accumulation by these plants of potassium, iodide and bromide against concentration gradients and by the lack of satisfactory knowledge concerning the physioligical processes involved at that time.

This impression gave rise to his life work, the metabolic absorption of plant nutrients. One of his earlier works on the selective accumulation of *Nitella*, a giant cell pond algae which was very useful in these works because of its simplicity of organs as compared to higher plants, is given in Fig.1. The work of OSTERHOUT on *Valonia*, a giant cell marine algae was also given as comparison.

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1 D. R. HOAGLAND: Lectures on the Inorganic Nutrition of Plants, Waltham, 1948.

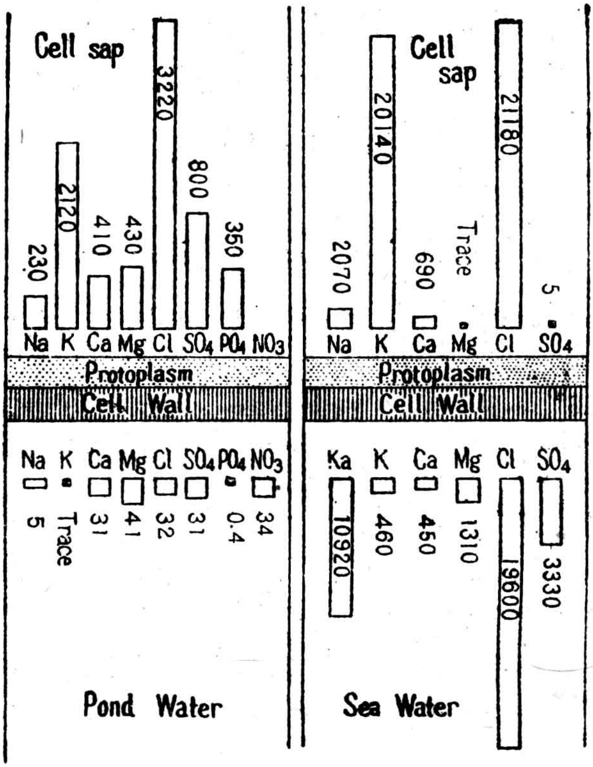

Fig. 1. Selective ion accumulation of *Nitella* and *Valonia*.
Nitella (HOAGLAND, 1923)
Valonia (OSTERHOUT, 1922)

From the Fig. it is evident that in *Nitella* the ion concentrations of the cell sap are always higher except for NO_3 than those of the pond water, especially with regard to K, PO_4 and Cl. In *Valonia,* however, the ion concentrations of the cell sap are higher for K, Ca and Cl but lower for Na, Mg and SO_4 than of the marine water. Thus, the concentration of K and Na showed marked contrast between inside and outside of the cell membrane and protoplasm.

HOAGLAND and many other subsequent workers observed that ion accumulation was always associated with metabolic activity such as aerobic respiration of the living cell and, if by any means normal metabolic activities were inhibited or interrupted, no accumulation i.e. inward movement against concentration gradients was observed.

This was proved not only with unicellular giant cell but also with ordinary higher plants with the help of delicate technique of normally metabolising excised root. One of his series of experiments is given in Figure 2. The accumulation of K, NO_3 and Br by excised barley root was severely reduced, when the partial pressure of oxygen in the gas mixture which was bubbled through aqueous medium decreased less than 10%. This accumulation proceeded parallel with the consumption of sugar in the root cell; this fact indicating the intimate connection between aerobic respiration and ion accumulation.

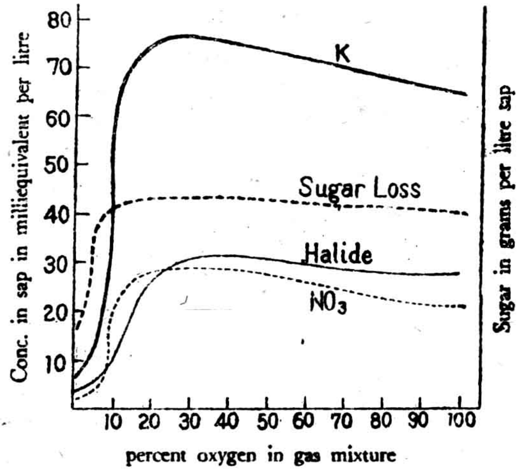

Fig. 2. Effect of oxygen partial pressure on the ion uptake and sugar consumption of excised barley root.
(Hoagland and Broyer, 1936)

Thermodynamics teaches us that the inward movement of ions against concentration gradients from outside of the cell to inside requires *work*. For this work aerobic respiration may be responsible. Thus, the role of aerobic respiration in ion accumulation would be, so to speak, a working pump in pumping up water from the well.

Although most recent works agree with that salt accumulation depends on metabolic activity, particularly on aerobic respiration, it is yet doubted whether both cations and anions are concerned or only anions are concerned, as proposed by Lundegardh in the

Anion respiration theory.

LUNDEGARDH's[1] anion respiration theory will be represented in the following equation:

$$Rt = Rg + kA.$$

where, Rt designates the total CO_2 in Mol respired by root (total respiration), Rg the basic respiration CO_2 in Mol which is indifferent to the anion respiration, A the anion respiration CO_2 in Mol and k a constant characteristic to respective anions.

His basic idea seems to be as follows. As the surface of the root membrane is negatively charged, only the negatively charged anions require some energy (Anion respiration) to pass inward through the membrane. The cations will pass through the membrane without any help of work, presumably by the cationic exchange.

Anyway, it is sufficient to point out here that ion accumulation is a phenomenon so intimately connected with metabolic activity or areobic respiration of root cells, that its inhibition or retardation results in a serious reduction of ion accumulation by higher plants.

2. Factors affecting ion accumulation by rice plant

Many factors may affect ion uptake by crop plants. Not only the environmental factors, such as temperature, light, supply of oxygen, ion concentration in the medium and pH, but also the factors pertinent to the plant itself, such as crop varieties, stage of development and so forth may more or less affect ion uptake by crop plants.

Effect of respiration inhibitors, particularly of hydrogen sulphide on the ion uptake of rice. Hydrogen sulphide often evolves in abundant quantities in the furrow slice of paddy rice field, especially if sulphate containing fertilisers such as ammonium sulphate, superphosphate and potassium sulphate are applied. The

1 H. LUNDEGARDH: Nature, *541*, 114~115 (1940)

reduction of sulphate to sulphide would be promoted by the presence of abundant organic matters such as green manures and composts. In addition, high temperature also contributes to its evolution.

In Japan, hydrogen sulphide has been considered as one of the principal inhibitors of nutrient uptake by rice plant, where the soil is sandy or iron deficient and hence belongs to the *degraded paddy soil,* which I will precisely refer to in the subsequent lectures (see p. 85). On the other hand, hydrogen sulphide is a well-known inhibitor of the iron carrying redox enzyme, for instance cytochrom, which is believed to exist widely in animal and plant bodies and to facilitate aerobic respiration.

If the theory of metabolic absorption of plant nutrients is basically correct, hydrogen sulphide evolving in the furrow slice may affect nutrients uptake by rice plant. This consideration led me and my associates[1)] to conduct the following studies.

Exp. I. Rice seedlings were transplanted to pots of 3.5 L capacity and grown for about two months by ordinary water culture technique. On 11th August 1950 the culture solution was replaced with a fresh solution containing 19 p.p.m. NH_4-N as ammonium sulphate, and one series of pot received twice bubblings of hydrogen sulphide, each time at the rate of approximately two bubbles per second and for ten minutes. After 26 hours, ammonium nitrogen remaining in the test solution was analysed by ordinary method along with the water transpired. The result is shown in Table 1 (a).

Subsequently, the same plants received approximately the same treatment with refreshed ammonium solution and hydrogen sulphide, the result of which is shown in Table 1 (b).

As seen from the Tables, hydrogen sulphide severely affected the absorption of ammonia and water, although it seemed more pronounced for ammonia than for water. Further, the inhibition proceeded intensively as the duration was prolonged.

Exp. 2. To know the extent of inhibition by hydrogen

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1 S. Mitsui, S. Aso, K. Kumazawa: Jour. Sci. Soil & Manure, Japan, 22, 46–53 (1951); S. Mitsui, K. Kumazawa: Ibid. in press.

TABLE 1. Effect of H_2S on the uptake of NH_4-N and H_2O by rice plant
(S. MITSUI, S. ASO, K. KUMAZAWA, 1951)

a) First 26 hours.

Treatment		Initial NH_4-N mg/pot	Decrease of NH_4-N mg/pot	Decrease of NH_4-N average	Decrease of H_2O g/pot	Decrease of H_2O average	Uptake of NH_4-N mg/pot	Uptake of NH_4-N per cent ratio	Uptake of H_2O g/pot	Uptake of H_2O per cent ratio	pH Initial	pH Final
Bubbled with H_2S												
planted	A	65.9	8.6	10.1	—	570	4.4	23	323	70	4.7	4.2
	B	68.5	11.5		570						4.7	4.2
not planted	A	65.9	5.4	5.7	230	243					4.7	4.7
	B	75.3	6.0		255						4.4	4.4
Not bubbled with H_2S												
planted	A	72.9	20.3	22.7	750	745	19.1	100	440	100	5.0	5.0
	B	73.6	25.0		740						3.9	3.9
not planted	A	64.3	2.8	3.6	260	305					5.0	5.0
	B	67.6	4.3		350						5.3	5.3

b) Second 24 hours.

Treatment		Initial NH_4-N mg/pot	Decrease of NH_4-N mg/pot	Decrease of NH_4-N average	Decrease of H_2O g/pot	Decrease of H_2O average	Uptake of NH_4-N mg/pot	Uptake of NH_4-N per cent ratio	Uptake of H_2O g/pot	Uptake of H_2O per cent ratio
Bubbled with H_2S										
planted	A	77.0	3.1	5.7	400	400	1.8	15	150	33
	B	76.9	8.3		400					
not planted	A	77.0	2.2	3.9	250	250				
	B	83.1	5.5		250					
Not bubbled with H_2S										
planted	A	75.5	18.0	17.7	575	550	12.1	100	450	100
	B	79.7	17.3		525					
not planted	A	73.8	4.6	5.6	100	100				
	B	71.6	6.5		100					

TABLE 2. Effect of H_2S concentration and contact period on the wilting of rice seedling. (The figures show the % of the wilted leaves)
(S. MITSUI, S. ASO, K. KUMAZAWA, 1951)

a) Long contact with H_2S solution.

Average concentration of S (ppm)	Contact period (hours)							
	0	24	43	48	66	90	139	288*
2.7	0	0	17	39	67	72	83	85
1.7	0	0	22	22	61	62	62	64
1.3	0	0	6	6	22	27	21	41
0.7	0	0	0	0	0	5	0	29
0.4	0	0	0	0	11	9	7	42
0.07	0	0	0	0	0	0	0	42
0.00	0	0	0	0	0	0	0	0

* Contact was discontinued after 90 hours.

b) Short contact with H_2S solution (2.9 ppm S).

Contact discontinued after	Time elapsed after contact discontinuation (hours)			
	24	48	96	240
0.5 hours	0	0	0	0
1.0 hours	0	0	0	0
2.0 hours	0	0	0	10
Contact continued 240 hours	0	0	60	67
Check	0	0	0	0

Remark: The figures are averages of triplicate runs.

sulphide with respect to its concentration and duration of contact the experiment given in Table 2 (a) (b) was conducted. In this case the number of wilted leaves was selected as the sign of damage, for this was confirmed as the definite sign of inhibition in ion uptake in the preceding experiment. The hydrogen sulphide was supplied as sodium sulphide with careful regulation of pH at 4.0 by the addition of H_2SO_4.

TABLE 3. Effect of H_2S on the uptake of NH_4-N, CaO, SiO_2, MnO, MgO, K_2O, P_2O_5 and H_2O by rice plant.

(S. MITSUI, S. ASO, K. KUMAZAWA, 1951)

Component elements and treatment.		Composition of culture solution. mean (ppm)	Composition of culture solution. standard deviation (ppm)	Uptake per 1 litre cult. sol. Calculation	Uptake per 1 litre cult. sol. mean (mg)	Uptake per 1 litre cult. sol. standard deviation (mg).	Percent uptake decreased by H_2S $\frac{S-O}{AB \text{ or } A} \times 100$
NH_4-N	AB	18.3	0.45	S–O***	3.9	0.43	
	S	13.8	0.31	AB–S***	4.5	0.53	46
	O	9.9	0.31	AB–O***	8.4	0.53	
CaO	A	35.9	0.31	S–O	0.2	0.25	
	S	28.9	0.18	A–S***	7.0	0.21	3
	O	28.7	0.18	A–O***	7.2	0.21	
SiO_2	AB	21.0	2.61	S–O*	8.4	3.5	
	S	18.3	2.47	AB–S	4.8	3.45	64
	O	9.9	2.47	AB–O**	13.2	3.45	
MnO	AB	5.6	0.12	S–O**	0.5	0.14	
	S	5.0	0.10	AB–S***	0.6	0.15	45
	O	4.5	0.10	AB–O**	1.1	0.15	
MgO	AB	32.9	0.29	S–O**	1.5	0.52	
	S	27.4	0.37	AB–S***	5.5	0.47	21
	O	25.9	0.37	AB–O***	7.0	0.47	
K_2O	AB	21.7	1.59	S–O***	16.5	1.84	
	S	24.5	1.30	AB–S	–2.8	2.05	120
	O	8.0	1.30	AB–O**	13.7	2.05	
P_2O_5	A	7.2	0.20	S–O***	5.6	0.16	
	S	9.0	0.11	A–S**	–1.8	0.23	143
	O	3.4	0.11	A–O***	3.8	0.23	
H_2O	C (start)	2900cc	15cc	S–O***	320cc.	21cc.	
	S(H_2S added)	2250cc.	15cc.	C–S***	650cc.	21cc.	33
	O (H_2S not added)	1930cc	15cc.	C–O***	970cc.	21cc.	

Remarks: 1) Analysis was conducted after making up to the initial 3 litre volume.

2) AB or A The composition of culture solution at the start.

S The composition of culture solution at the end in the plot with H_2S.

O The composition of culture solution at the end in the plot without H_2S.

*** 0.1% level of significance.

** 1% level of significance.

* 5% level of significance.

As seen from Table 2 (a) (b), the inhibition is a function of the concentration of hydrogen sulphide and the duration of contact. If the duration of contact continued sufficiently long, the wilting set in in the end even by the extremely dilute (0.07 p.p.m.) solution. On the other hand, even by the comparatively concentrated (2.9 p.p.m.) solution the symptom did not appear if the duration of contact remained within two hours.

Exp. 3. Table 3 shows the result of experiment, in which the absorption of NH_4, CaO, SiO_2, MnO, MgO, K_2O, P_2O_5 and H_2O was analysed respectively. The initial pH of the culture solutions was controlled approximately at 5. Hydrogen sulphide was bubbled through the culture solutions at the rate of two bubbles per second for thirty minutes. The initial concentration of hydrogen sulphide was ca. 260 p.p.m., but it rapidly decreased to the final concentration of 7 p.p.m. due to possible volatilisation and oxida-

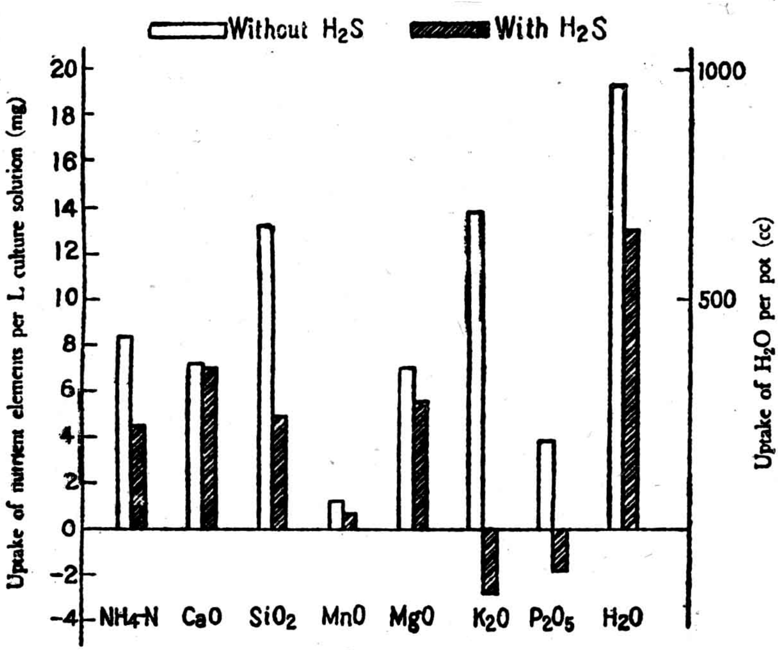

Fig 3. Uptake of H_2O and other nutrient elements as influenced by H_2S
(S. Mitsui et al. 1951)