18. NUTRITIONAL DISORDERS AND THEIR COUNTERMEASURES IN CEYLON

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Introduction

Ceylon is an island with an area of 25,332 square miles situated between 0° and 10° North Latitude, off the Southern tip of India. The length and breadth of the island are approximately 270 and 140 miles respectively.

Background

(1) Climate

There is very little seasonal variation of temperature in the island. The average temperature on the coastal plain of the South-West and South-East is between 80 - 81°F (27°C), while that over the Northern plain is between 81 - 83°F (27 - 28°C). The distribution of temperature is to a large extent controlled by the relief of the land, the average approximate temperatures at 1,000, 3,000 and 6,000 feet being 77°F, 70°F and 60°F respectively.

The rainfall of the island is derived from monsoons, local thunderstorms and cyclones. The Western part of the island gets its rainfall mostly between May to October and the Northern and Eastern parts of the island get their rainfall mostly from December to February. Thunderstorms are frequent during October to November and during March to April.

(2) Rainfall or Agroclimatic Zones

Three main rainfall or agroclimatic zones may be recognized in Ceylon (Figure 1). On the South-West is the wet zone which receives an annual rainfall between 100 to 200 inches. The lowland plains of the North and East include the dry zone where the annual rainfall is less than 50 - 75 inches. The intermediate zone which is situated in between the wet zone and the dry zone receives an annual rainfall around 75 - 100 inches which is more or less evenly distributed during the year. The wet zone may be further divided into the low-country which is below 500 feet elevation, the mid-country which is between 500 feet and 3,000 feet and the up-country which is above 3,000 feet in elevation.

(3) Highland soils

The predominant great soil groups of the wet zone, where rainfall exceeds evaporation, are (1) the red-yellow podzolic soils and various sub-groups, and (2) the reddish brown latosolic soils. In the dry zone, where evaporation exceeds rainfall the principle great soil groups are (1) the reddish brown earths, (2) the non-calcic brown soils and (3) the red-yellow latasols (Moorman and Panabokke, 1961). Rice is grown on all soils if water is available.

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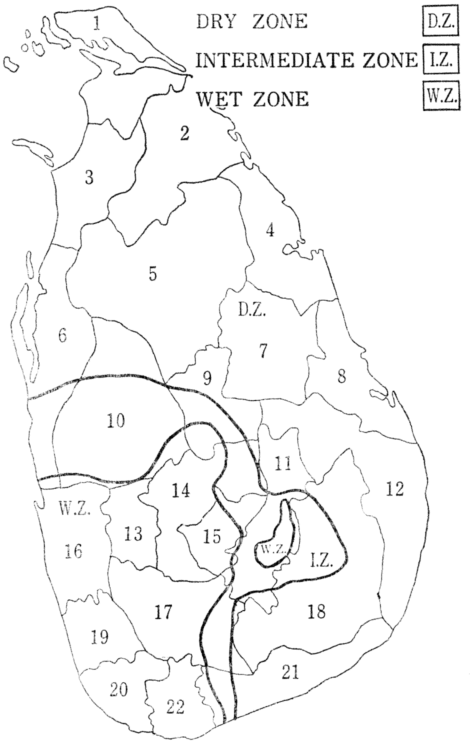

1. JAFFNA
2. VAVUNIYA
3. MANNAR
4. TRINCOMALEE
5. ANURADHAPURA
6. PUTTALAM
7. POLONNARUWA
8. BATTICALOA
9. MATALE
10. KURUNEGALA
11. BADULLA
12. AMPARAI
13. KEGALLE
14. KANDY
15. NUWARA ELIYA
16. COLOMBO
17. RATNAPURA
18. MONERAGALA
19. KALUTARA
20. GALLE
21. HAMBANTOTA
22. MATARA

Fig. 1. Map of Ceylon Showing the Major Agroclimatic Zones and Administrative Districts.

(4) Rice

There are two rice growing seasons in Ceylon. The major season (Maha in Sinhalese) extends from September to March, while the other season (Yala in Sinhalese) extends from April to August. In the wet zone two crops of rice are usually grown during the year, but in the dry zone only the Maha crop is possible unless irrigation facilities are available. During the Maha long aged varieties (5 to 6 months) are usually grown while early maturing (3 to 4 months) varieties are grown in the Yala.

The total acreage of rice in Ceylon is approximately 1,550 thousand of which about 900 thousand are situated in the dry zone and the balance in the wet zone.

The average yield of rice in Ceylon is approximately 46 bushels paddy per acre (approximately 2,300 kg/ha.). The country needs approximately 86 million bushels of rice per year but produces only about 60 million. Of this the dry zone produces between 35 to 40 million bushels while the balance is produced in the wet zone. The balance requirement of rice is imported, and this is a major economic problem. An immediate task of the agriculturist in Ceylon is to increase rice production.

(5) Rice Soils

Most rice soils of Ceylon are of alluvial origin and occupy low lying areas in the flood plains of rivers and their tributaries. The parent material of these soils is highly weathered, and soils are poor in available plant nutrients. On most soils therefore the minimum nutritional requirements of the crop have to be supplemented every season with fertilizers in order to obtain economic yields.

The fertility characteristics of rice soils of Ceylon have been studied by Panabokke and Nagarajah (1964), and range values of some characteristics for the various administrative districts in the main agroclimatic zones are presented in Table 1. Recently, the fertility characteristics of some rice soils in Ceylon have also been studied by Kawaguchi and Kyuma (1967).

The rice soils of the wet zone are strongly acid and well supplied with organic matter. They contain a fair amount of nitrogen, in contrast to the condition usually found in the dry zone. In the low lying areas by the coast are the high humic peaty soils. The soils of the wet zone are poor in available phosphorus, exchangeable potassium and other bases; and phosphorus and potassium fertilizers have to be regularly added. On these soils, split-applications of nitrogen and potassium are better than single applications at or before planting.

The rice soils of the intermediate zone are strongly to slightly acid in reaction. They are low in organic matter and nitrogen and fairly low in available phosphorus and exchangeable potassium. Nitrogen, phosphorus and potassium fertilizers are always recommended

Table 1. Model Range Values of Rice Soils in Various Administrative Districts of Ceylon (Panabokke and Nagarajah, 1964)

Major agroclimatic zone	Administrative district	pH 1 : 1 soil : water	Total nitrogen percent	Avail. P_2O_5 (Olsen's) lbs/acre	Exch. K m.e./100g	C/N ratio
Dry zone	Jaffna	5.3 - 8.3	<0.05	5 - 60	<0.10->0.30	<8
	Vavuniya	6.0 - 6.5	0.05 - 0.10	5 - 15	0.10 - 0.30	8 - 10
	Mannar	6.0 - 8.3	0.05 - 0.10	5 - 15	0.25->0.30	<8
	Trincomalee	5.3 - 7.2	0.10 - 0.15	5 - 30	<0.10 - 0.15	8 - 10
	Anuradhapura	6.0 - 7.2	0.05 - 0.10	5 - 30	0.15 - 0.30	10 - 15
	Puttalam	4.5 - 6.5	0.05 - 0.10	5 - 30	<0.10 - 0.30	10 - 15
	Polonnaruwa	6.0 - 7.2	0.05 - 0.10	5 - 30	<0.10 - 0.15	10 - 15
	Batticaloa	5.3 - 5.9	0.05 - 0.10	5 - 15	<0.10 - 0.15	<8
	Amparai	4.5 - 7.2	0.05 - 0.10	5 - 60	<0.10 - 0.30	8 - 10
	Hambantota	5.3 - 6.5	0.10 - 0.15	15 - 60	0.10 - 0.30	10 - 15
Intermediate zone	Matale	5.3 - 6.5	0.10 - 0.15	5 - 45	<0.10 - 0.15	10 - 15
	Kurunegala	4.5 - 6.5	0.05 - 0.10	5 - 30	<0.10 - 0.20	
	Moneragala	5.3 - 6.5	0.10 - 0.15	5 - 15	<0.10	<8
Wet zone	Badulla	4.5 - 6.5	0.15 - 0.25	5 - 45	<0.10 - 0.15	10 - 15
	Kegalle	4.5 - 5.2	0.10 - 0.15	15 - 30	<0.10	10 - 15
	Kandy	4.5 - 5.9	0.10 - 0.15	15 - 45	0.10 - 0.15	10 - 10
	Nurara Eliya	4.5 - 5.9	0.10 - 0.15	15 - 60	0.10 - 0.25	10 - 15
	Colombo	4.5 - 5.2	0.15 - 0.25	15 - 30	<0.10	10 - 15
	Ratnapura	4.5 - 5.9	0.15 - 0.25	5 - 30	0.10 - 0.15	15 - 25
	Kalutara	4.5 - 5.2	0.15 - 0.25	15 - 30	<0.10	15 - 25
	Galle	4.5 - 5.2	0.15 - 0.25	5 - 30	<0.10 - 0.30	15 - 23
	Matara	4.5 - 5.2	0.15 - 0.25	5 - 30	<0.10 - 0.25	10 - 15

on these soils.

In the dry zone the rice soils are slightly acid to neutral in reaction and generally lighter in texture than those of the wet zone. They are poor in water holding capacity. These soils are relatively poorer in nitrogen than soils of the wet zone. These soils are generally poorly supplied with available phosphorus and fairly low to medium in exchangeable potassium. Nitrogen, phosphorus and potassium fertilizers are always recommended for rice on these soils although response to potassium may not always be observed on these soils.

Nutritional Inadequacies in Soils and Responses to Fertilization

As stated earlier the rice soils of Ceylon are generally poor in available plant nutrients and farmers are advised to apply nitrogen, phosphorus and potassium fertilizers to soils every season. Fertilizer use for rice in Ceylon has been steadily increasing since 1956. This is mostly due to incentives provided by the Government. Fertilizers are sold at subsidized rates to farmers to encourage them to obtain high yields.

(1) Nitrogen

One of the commonest nutritional disorders is inadequate nitrogen for rice. Nitrogen deficiency is common and responses to nitrogen fertilization have been reported on most rice soils of Ceylon. As to be expected the soils of the dry zone are poorly supplied with nitrogen compared to those of the wet zone (Table 1). This is largely due to the higher daily temperature and relatively better drainage that promote the rapid mineralization of organic matter in the dry zone. Therefore soils of the dry zone generally require more nitrogen than those of the wet zone. The ill-drained soils require the least amount of supplemental nitrogen. In the fertilizer recommendation for rice due consideration is given to the source of nitrogen best suited to conditions that prevail in a particular soil.

Prior to 1956, the form of nitrogenous fertilizer recommended for rice on all soils was ammonium sulphate. However from 1956 onwards urea was used in place of ammonium sulphate on soils low in iron. This is in order to avoid the harmful effects of hydrogen sulphide that would be formed from the reduction of sulphates in such soils. Experiments with different forms of nitrogen fertilizers have shown that ammonium sulphate was inferior to urea on the imperfectly drained acid clays and loams of the low country wet zone which are generally high in organic matter (Ponnamperuma, 1960c). Urea has also been shown to me more effective than ammonium sulphate as a source of nitrogen on the acid sandy soils in the Batticaloa district of the dry zone (Jayasekara and Ariyanayagam, 1962). On some neutral to slightly alkaline soils of the dry zone however, ammonium sulphate has been found to be more effective. This may most probably be due to loss of urea nitrogen and toxicity of ammonia from hydrolysis of urea. Urea is now recommended for all soils that are sandy, peaty or are rich in kaolinitic clay minerals as these soils are relatively poor in iron content. Recent experiments with various nitrogenous fertilizers have shown that ammonium chloride performed better than urea, ammonium sulphate, ammonium-sulphate-nitrate, calcium-ammonium-nitrate and ammonium nitrate for several seasons at three stations in the wet zone, and two stations and in cultivators' fields in the dry zone (Rodrigo *et al*. 1969). Ammonium-sulphate-nitrate has been found to be superior to urea or ammonium sulphate on the ill-drained soils of Ratnapura district of the wet zone while on the well drained soils of the district ammonium sulphate was found to be better (Thenabadu, 1968a).

Studies on the efficiency of time of application of nitrogenous fertilizers for rice have shown that split applications are superior to single applications. The current recommendations for rice are therefore to apply nitrogenous fertilizers in two top-dressings on all soils as follows :

1) First top-dressing - Two weeks after sowing or planting.
2) Second top-dressing - For three months varieties - six weeks after sowing.
   For four months vaieties - ten to eleven weeks after sowing or eight weeks after transplanting.
   For five-and-a-half months varieties - sixteen to seventeen weeks after sowing or fourteen weeks after transplanting.

It may be added that, formerly a top-dressing of nitrogen was recommended at the time of heading. But this is now not recommended because farmers are reluctant to get into the fields at heading time.

The need for balanced fertilizer recommendation is seen from the results of an experiment in the wet zone. No response to nitrogen was observed beyond the rate of 40 lbs N per acre given as urea with phosphorus or potassium supplied at levels between 80 to 100 lbs per acre P_2O_5 and K_2O. However, when both phosphorus and potassium were increased to 100 lbs each of P_2O_5 and K_2O a response to 80 lbs N per acre was recorded (Fernando, 1961).

Results of experiments using isotopes, conducted in the co-ordinated study of rice fertilization with the Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture of the United Nations, confirmed past knowledge obtained through conventional methods of research while also throwing fresh light on our prevalent concepts. An experiment conducted in both the wet zone and dry zone showed that a fertilizer application two weeks before primordial initiation resulted in the greatest uptake of nitrogen (Nagarajah and Al-Abbas, 1965a). This was confirmed in a subsequent experiment (Kathirgamathaiyah, Thenabadu and Al-Abbas, 1968) where it was also found that plants absorbed most nitrogen from urea in comparison to ammonium sulphate, ammonium nitrate or sodium nitrate. The results of another experiment conducted in the dry zone showed that the efficiency of fertilizer nitrogen was increased by placing it at a depth of 5 cm at transplanting than when applied in rows on the surface (Nagarajah and Al-Abbas, 1965b). In a subsequent experiment conducted in the dry zone it was shown that the highest yields were obtained when ammonium sulphate was placed 15 cm below the surface while the lowest yields were obtained when the fertilizer was applied in rows on the surface (Thenabadu, Jauffer and Willenberg, 1968).

(2) Phosphorus

Most rice soils of Ceylon are not adequately supplied with available phosphorus (Table 1) (Panabokke and Nagarajah, 1964 ; Takijima,1969) and generally there has been responses to phosphorus fertilization on most soils. On the acid and strongly acid, moderately well drained to poorly drained loams and clays of the wet zone no significant differences on rice yields were observed from the use of soft rock phosphate (Saphos phosphate), ordinary superphosphate, basic slag or bone meal (Chandraratna and Fernando, 1954 ; Ponnamperuma, 1960c), or between rock phosphate and bone meal (Rodrigo *et al.*, 1967). Hence rock phosphate, the cheapest form of phosphate fertilizer, is recommended for rice in the wet zone. The recommendation for phosphorus application is before sowing or planting, preferably at the time of second ploughing. Under the acidic conditions that prevail in soils of the wet zone the rock phosphate is rendered available to plants ; but if conditions for solubilization are not favourable plants are likely to suffer from phosphorus deficiency. Fused magnesium phosphate has been reported to perform well, especially in ill-drained boggy soils (Takijima, 1968).

On the relatively less acidic soils of the intermediate zone and dry zone concentrated superphosphate has been found to be better than rock phosphate for rice (Weerawickrema, 1968).

(3) Potassium

The rice soils of the dry zone and intermediate zone of Ceylon are relatively richer in exchangeable potassium than those of the wet zone (Table 1). This is mostly because potassium and other bases are easily removed from weathering rocks and soils by leaching due to excessive rainfall in the wet zone. In the dry and intermediate zones fertilizer experiments have revealed little response to potassium with rice (Ponnamperuma, 1960c). Nevertheless, potassium is recommended for rice on all soils in these zones because of its role in plant growth and prevention of disease.

On the humic rice soils of the wet zone top-dressing of potassium have given high yields (Fernando, 1961). Little or no response was observed when 100 lbs potassium per acre were all applied at transplanting, while significant yield increases were obtained when half of this was applied at planting and the balance was applied eight weeks later. Further experiments have shown that 80 lbs potassium per acre applied at transplanting had no effect on yield but a split-application of one-third this quantity at planting and two-thirds either at tillering, at pollen mother cell stage or at heading gave a significant yield increase of nine bushels per acre (approximately 450 kg/ha.).

(4) Micro-nutrients

Fertilizer trials have indicated that copper and boron may be inadequate, for optimum rice yields in the soils of the wet zone, while copper, zinc and molybdenum may be limiting rice production in some parts of the dry zone (Ponnamperuma, 1960a).

(5) Silicon

Although silicon is not generally considered an essential element for all plants there is evidence that adequate supplies of available silica are necessary for high rice yields. In addition to its effect on the growth and yield, the role of this element in increasing the resistance of plants to fungal disease is also known. The strongly acid lateritic soils of the low country wet zone are deficient in silica. In the low country wet zone an average yield increase of 66.5 per cent has been obtained by the application of silica at 5 cwt. per acre (Ponnamperuma, 1960a); and significant yield increases during several subsequent seasons which have been obtained on these soils indicate a cumulative benefit of silica application (Rodrigo, 1964).

(6) Granular-Compound-Fertilizers

Granular-compound-fertilizers containing the three fertilizer elements (N, P and K) have been found to be very satisfactory for rice on the swampy and boggy ill-drained soils of the wet zone (Thenabadu, Wickremasinghe and Perera, 1967; Thenabadu, 1968b). Their ease of application, slow nutrient releasing property and the fact that farmers are compelled to apply balanced amounts of all three plant nutrients (instead of only nitro- gen which most farmers apply), are the advantages of these fertilizers which are becoming popular in the country. More recent experiments have confirmed the above findings (Takijima, 1968).

Nutritional Disorders Caused by Physiological Problems

In the wet zone an appreciable extent of the rice soils is swampy, ill-drained and high in organic matter (Panabokke and Nagarajah, 1964). This is due to inadequate drainage of the excess rain water which causes flooding and water-logging. Poor soil drainage is also encouraged by impervious clay substrate in the lower regions of the soil profile (Thenabadu, 1960a) Common physiological problems that cause nutritional disorders in the wet zone of Ceylon are, excess acidity, hydrogen sulphide toxicity and bronzing.

(1) Excess Acidity

Low soil pH and poor base saturation status of soils limit rice yields in some areas of the wet zone. Lime has proved to be a suitable amendment and has given appreciable yield increases on the strongly acid (pH 4. 4) lateritic soils of the wet zone (Ponnamperuma, 1960b). Slaked coral lime has been found to be superior to ground coral limestone or ground dolomite. A single application of 6 tons per acre of slaked lime was found to give an increase of over 700 lbs (approximately 14 bushels) per acre paddy on soils of the low country wet zone, the benefits being sustained for four seasons. In some locations nitrogen and phosphorus fertilizers were found to be superfluous during the first season of lime application. On the less acid soils of the mid country wet zone the optimum level of lime was approximately 3 tons per acre. In an investigation on the brown acid lateritic soil, rice responded to 3 tons per acre slaked lime; the response to lime alone being 11 bushels per acre. The increase in yield was more than doubled (26 bushels per acre or approximately 1500 kg/ha.) by the further addition of 40 lbs N, 84 lbs P_2O_5 and 100 lbs K_2O per acre (Thenabadu, 1960b). On the very poorly drained humic soils of the wet zone however, there has been no response to lime (Ponnamperuma, 1960b; Thenabadu, 1960b).

(2) Hydrogen Sulphide Toxicity

Hydrogen sulphide, a product of the anaerobic reduction of sulphates and of the anaerobic decomposition of proteins, is a well known respiratory inhibitor common in sandy and peaty soils of Ceylon which are poorly supplied with iron. Root rot caused by hydrogen sulphide may cause deficiency of nutrients such as potassium, magnesium, manganese and of silica (Baba, 1958). A correlation between hydrogen sulphide in soil soulution and the degree of bronzing in plants has been reported (Inada, 1965a; Mulleriyawa, 1966). Sulphate containing fertilizers are therefore not recommended for rice on soils liable to be affected by hydrogen sulphide.

(3) Bronzing

A physiological disease known as "Bronzing" or "Browning" occurs in the wet zone of the island, when the older leaves of the plants acquire a reddish-brown to purplish-brown colour, spreading from the tip downwards. In extreme cases these leaves may ultimately die. In the early stages of growth this disease decreases plant height, and grain yields may be reduced even if plants are affected at later stages of growth. Accumulation of reduced products in the soil, especially ferrous iron, has been considered to be the cause of "Bronzing". Ferrous iron at a concentration of 525 ppm in soil percolates was found to be toxic to rice plants (Ponnamperuma, 1955). Lime has been recommended as an effective remedy for this problem because it prevents the build up of a high concentration of iron in the soil solution, (Ponnamperuma, 1958). The beneficial effects of liming in reducing the severity of bronzing has been confirmed by other investigators who further found that straw compost was also effective in preventing this disease (Ota and Yamada, 1962; Inada, 1965a).

Further, evidence has also been obtained to indicate that excess aluminium together with inadequate calcium could be responsible for this disorder. Lower concentrations of calcium, potassium, magnesium, manganese and silica have been reported in affected plants;

and it has been found that application of potassium (in addition to lime and compost) was beneficial in lessening the severity of bronzing. Symptoms of bronzing were produced easily when roots or cut leaves of rice plants were exposed to a solution of ferrous iron, or when plants were grown in solutions containing high concentrations of aluminium and low concentrations of calcium (Ota and Yamada, 1962 ; Ota, 1968a ; 1968b).

A close correlation between iron content in leaves and the degree of bronzing has been reported (Inada, 1965a ; 1965b). A three to six fold increase of this element has been observed in bronzed leaves in comparison with healthy leaves. Increased contents of calcium and decreased amounts of potassium, manganese and silica has been reported in bronzed leaves. Further, a close relationship between degree of bronzing and total sulphide contents, especially hydrogen sulphide, of the soil solution has been observed. The content of aluminium in bronzed leaves was also high, but there was no clear relationship between this element and the severity of bronzing. Recent studies have shown that iron toxicity may be a direct cause for this disorder especially when the availability of soil potassium is low (Mulleriyawa, 1966). In addition excess hydrogen sulphide may predispose the plants to bronzing.

(4) Salinity and Alkalinity

In the dry zone and intermediate zone, salinity and alkalinity are common problems that reduce rice yields.

The indications are that the acreage affected by these problems is increasing annually. In some areas salinity is due to flooding of sea water, but in other areas salt accumulation is caused by capillary action due to inadequate drainage, a high water-table and evapotranspiration of excess water.

Reclamation of saline fields, by flooding and leaching away of the excess salt, presents practical difficulties. These are the lack of sufficient water and the physiographic location of the fields which makes good drainage difficult. Application of gypsum at 10 to 12 cwt. per acre is recommended for alkaline fields but this treatment is also ineffective if sufficient water is not available for leaching the soil to remove the displaced sodium. The use of salt resistant varieties of rice appears to be the solution to the problem at present.

Duscussion

Y. Takijima, Japan : In my experiments which were conducted in Ceylon I found that application of slags was effective in increasing grain yields of indica varieties of rice. However, there did not appear to be any good correlation between yield increases and the greater absorption of silicon by plants as has been reported with japonica varieties. I wish to know the probable reason for this difference especially in view of any physiological differences that may exist between these two groups of rice.

Answer : I am not aware of any differences between indica and japonica varieties as far as silicon nutrition is concerned. I wish to invite comments from the plant physiologists.

(Comment) S. **Yoshida**, IRRI : It appears there is no difference between indica and japonica varieties of rice in their abilities to absorb silicon from the soil. When vigorous-growing leafy indica varieties are compared with slow-growing japonica varieties, it is found that the content of silicon in the former tends to be lower than that of the latter. This may be due to greater growth of indica varieties (dilution effect).

Soebijanto, Indonesia : Did you find any differences in yield response between ammonium and nitrate containing granular-compound-fertilizers in the wet zone.

Answer : So far I have the information from only one location for one season (Bombuwela, Maha season 1968/69). In this experiment I did not observe any significant differences between ammonium and nitrate containing granular-compound-fertilizers.

Soebijanto, Indonesia : How do farmers overcome the hygroscopicity of ammonium-sulphate-nitrate during storage?

Answer : We have still not recommended ammonium-sulphate-nitrate to farmers. In any case the ammonium-sulphate-nitrate we used was not very hygroscopic.

S. K. De Datta, IRRI : I think one of the reasons for the poor performance of urea in the dry zone soils of Ceylon may be due to higher volatilization losses of ammonia rather than ammonia toxicity.

Answer : Yes, volatilization losses of ammonia could be appreciable on these high pH soils, but I thought rice seedlings could also be damaged by ammonia gas. Apparently this was a misconception. Thank you.

K. Kawaguchi, Japan : Low soil pH (around 4.4) may not be a direct cause for poor growth of rice. Could aluminium toxicity be the main cause of poor growth on these acid soils of the wet zone?

(Comment) **Y. Ota**, Japan : Yes. Aluminium toxicity could be the cause of poor growth on these soils.

S. Matsushima, Japan : Which is the actual cause of Bronzing - is it iron or aluminium? Ponnamperuma and Inada state it is iron while Ota states it is aluminium. I wish to have a clarification on this.

Answer : From these reports it appears that symptoms of bronzing could be caused by high concentrations of either ferrous iron or aluminium. It is probable that excesses of both ferrous iron or aluminium could be toxic to the roots of rice plants making them incapable of selectively absorbing nutrients. Hydrogen sulphide or low molecular weight aliphatic acids or phenols which may accumulate in some rice soils could interfere with the capacity for selective absorption by rice roots. Under such conditions excess of iron or aluminium could get into plants in a passive manner causing characteristic symptoms of bronzing.

A. Tanaka, Japan : The symptoms of calcium deficiency or aluminium toxicity produced in water culture experiments are totally different from those of bronzing. Further, the concentration of aluminium in the soil solution of a soil where bronzing occurs is low and that of calcium is not very low. I wish to have more convincing evidence that bronzing is related to calcium deficiency or aluminium toxicity.

(Comment) **Y. Ota**, Japan : In my opinion the primary cause of bronzing is aluminium. The other causes are secondary.

I observed that the occurrence of bronzing was closely related to rainfall ; the disease appeared soon after a heavy rainfall, though it disappeared during a long spell of continuous rainfall, and that the bronzing was seen in the field overflowed with ferrugious lateritic soil which flew in from the adjacent highland by heavy rain. Furthermore, it was recognized that the bronzing was experimentally induced by application of ferruginous lateritic soil, and that the occurrence of bronzing was closely related to the aluminum content in the ferruginous lateritic soil.

In diseased plants a great quantity of aluminum was detected in roots, and the amount of aluminum in root showed a close positive correlation to the grade of bronzing. The roots of the diseased plant became coarse and scanty, and turned dark brown. This symptom is quite similar to the aluminum toxicity described in othe crops. Content of calcium in diseased plants was low and had a high negative correlation to the grade of bronzing. It is already known that aluminum causes a specific inhibition of calcium absorption by the rice plant. The inhibition in absorption and translocation of phosphorus owing to the fixation of phosphorus by alminum was observed. In a solution culture experiment, bronzing was induced artificially by treating plants with aluminum under the conditions of calcium deficiency.

Based on the above facts, it is concluded that active aluminum in combination with calcium deficiency in the soil is responsible for the cause.

(Comment) **A. Tanaka**, Japan: Upland soils may have high concentrations of aluminium but on submergence the concentration of active aluminium becomes low.

(Comment) **Y. Takijima**, Japan: From observations of recent trials carried out in Ceylon on this problem of bronzing I found that increased application of potassium together with phosphorus as fused magnesium phosphate had a most remarkable effect. Drainage and liming treatments would occupy second place in remedying this condition. Of the latter treatments drainage and soil drying was more effective.

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