Nutritional Disorders of the Rice Plant in Asia

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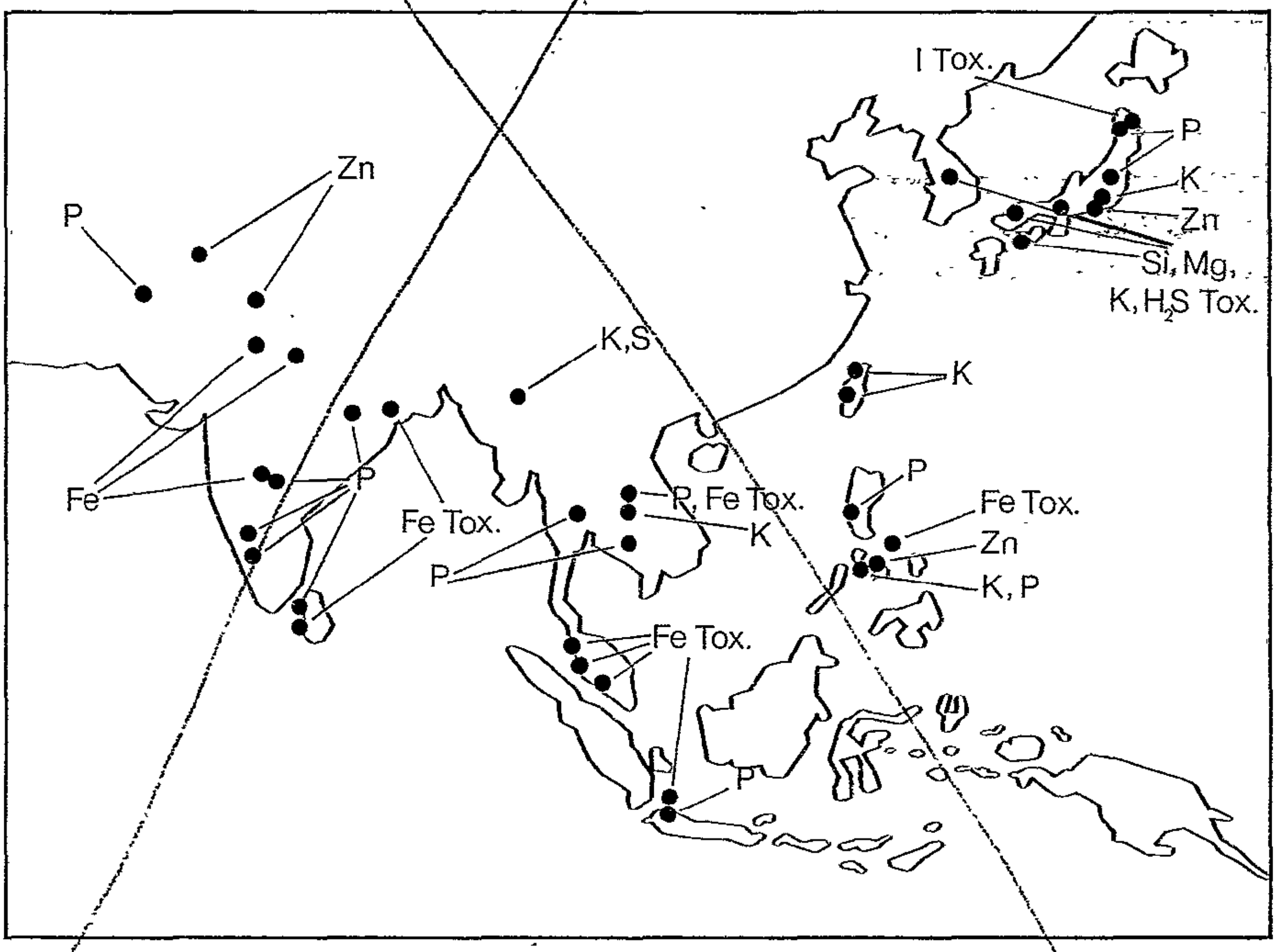

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Introduction

From the standpoint of plant physiology, problems of tropical rice production in Asia can be divided into two groups: low yields from plants with vigorous vegetative growth and low yields from plants with inadequate vegetative growth.

Tall, droopy-leaved, vigorous-growing indica varieties tend to produce excessive vegetative growth when well fertilized. Their leaves become more droopy. As a result, serious mutual shading sets in, the plants usually lodge, and the grain yield becomes disappointingly low. Studies at IRRI have demonstrated that short stems, erect leaves, and non-lodging are desirable plant characters for rice varieties. These characters help the plant make maximum use of solar energy and hence yield more when nitrogen is applied (*118*, *128*). Thus the problem of low yields from plants with vigorous vegetative growth can be solved by planting an improved variety and growing it using good agronomic practices.

The second type of problem, low yields from plants with poor vegetative growth, has two major causes. One is the supply and control of water, a subject beyond the scope of this publication. The other is nutritional disorders—deficiencies and excesses of some elements. This subject is closely associated with the nature of the soil and the terrain in which it is found.

Since rice is usually grown in submerged soils, scientists have attempted to relate nutritional disorders of the rice plant to the chemistry of submerged soils.

Nutritional disorders of the rice plant occur under a variety of soil conditions. The disorders considered to be caused by submerged soil conditions are generally called "physiological diseases" (*112*, *113*). These frequently occur in fields where drainage is impeded and products of anaerobic decomposition have accumulated under the reductive soil conditions.

A number of "physiological diseases" have been reported from various rice-growing countries. However, the causes of most have not been precisely identified and no comprehensive comparative study of "physiological diseases" has been made. Moreover, some disorders previously regarded as "physiological diseases" have recently been identified as virus diseases (*23*, *25*, *26*, *53*, *80*, *81*, *114*). Thus, it becomes necessary to re-examine the "physiological diseases" critically.

Most "physiological diseases" are considered related to the development of highly reduced soil conditions. However, a reduced condition, as expressed by Eh *per se*, may not cause the disorder. Rather, chemical changes under reduced conditions which induce deficiency or excess of nutrients may cause the disorder.

There are also large areas where the growth of rice is not satisfactory due to inherent soil factors. If a soil is absolutely low in some essential elements or abnormally high in others, the growth of a crop cannot be normal, whether it is an upland or lowland crop. Thus, nutritional disorders must be examined not only in relation to reduced soil conditions, but also in relation to the inherent nature of the soil. Moreover, there are interactions between the toxic effect of various substances produced under reduced conditions and the nutritional conditions of the plants. Thus, it is impossible to discuss "physiological diseases" without examining the general nutritional status of the plants.

We believe that nutritional disorders of rice should be discussed in terms of elements directly causing deficiencies or toxicities, rather than in terms of Eh or the anaerobic nature of submerged soils. Possible causes of nutritional disorders:

- Deficiency of nutrient elements: N, P, K, Fe, Mn, Zn, Si, etc.
- Toxicity of elements: Fe, Mn, B, Al, etc.
- Toxicity of substances accumulated in the soil under reduced conditions: sulfide, organic acids, carbon dioxide, etc.
- High salt injury: Na salts, etc.

Since no thorough comparative survey of nutritional disorders in the countries of Asia previously existed, we made a survey to identify and classify the problems. Proper diagnosis of nutritional disorders at the site should enable us to decide where and what type of field experiments should be initiated to examine the problems in more detail, and to apply research results to the improvement of rice production.

The main purposes of this publication are to describe our observations of rice disorders in Asia ,and to discuss them in relation to plant nutrition, soil chemistry, and what is known about "physiological diseases." Detailed information on greenhouse and analytical techniques has been omitted in the interest of brevity and continuity. These techniques are described elsewhere in the authors' papers.

Reported "physiological diseases" of rice

It is often assumed that disorders given the same name in different countries are the same disorder. Since one of our primary purposes was to verify that disorders described by different names were in fact different, and that disorders described by the same names were identical, we have attempted to describe the symptoms of the disorders reported from different countries as precisely as possible.

Bear in mind, too, that names of disorders are usually derived from visible symptoms expressed in local languages. As a result, they are not scientifically well defined.

BURMA

Amyit-Po (*3, 47, 112, 113*).

Amyit-Po literally means root disease. It was found in Mandalay, Upper Burma in 1938. Where the disease was observed, the soil was heavy clay and alkaline.

The affected plant turns dark-green about a month after transplanting and subsequent growth is retarded. The lowest leaves tend to drop off. The plant produces a normal number of tillers but many panicles remain sterile. The disease appears on low-lying patches in the field and the symptoms have been reproduced in pot experiments using unrotted cow dung. Applying superphosphate is beneficial (*47*). According to Aiyar (*3*), the symptoms of Amyit-Po are similar to those of potassium-deficient plants grown in culture solution. Application of calcium sulfate or calcium phosphate does not control the disease but affected plants respond to application of potassium sulfate. Affected plants have low potassium but high iron content. The evidence suggests that Amyit-Po is caused by potassium deficiency related in some way to reductive conditions. It should be noted that no brown spots appear in this disease.

Myit-Po (*47, 112, 113*)

Literally, Myit-Po has the same meaning as Amyit-Po. In extreme cases, no growth is apparent and the plant gradually withers away within a month. Tillers are not formed. Application of phosphates before or after transplanting is very effective. This disorder appears to be an expression of phosphorus deficiency.

Yellow leaf (*2, 47, 112, 113*)

Leaves turn yellow about a month after transplanting and remain stunted. The disease occurs in patches. Application of fertilizers containing sulfate to the water at the base of affected plants revives them to a normal condition. The disease was thought to be related to manganese deficiency (*113*), probably because of the tendency of sulfate fertilizer to lower soil pH, thereby increasing availability of manganese in the soil. However, it appears that yellow leaf is due to sulfur deficiency. Experimental evidence presented by Aiyar (*2*) seems sufficient to support this conclusion. He tested the effects of magnesium sulfate, calcium sulfate, iron pyrites, flowers of sulfur, ammonium sulfate, and superphosphate on the disorder and found that all of these sulfur-containing fertilizers corrected the chlorosis. Affected plants contained less than 0.1 percent sulfur and no detectable sulfate by benzidine test. As far as we are aware, Aiyar's paper is the only one describing sulfur deficiency of rice in the field.

CEYLON

Bronzing (*27, 33, 34, 78, 79, 86, 87, 122, 136*)

The typical symptom of bronzing is the appearance of many small brown spots in dark-green leaves, starting on the tips of lower leaves and spreading to the basal parts. In severe cases, the brown discoloration appears even on the top leaves. The tints of the affected leaves vary with variety; they may be purplish, orange, yellowish brown, reddish brown, brown, or purplish brown. The roots of affected plants are coarse, sparse, dark brown, and damaged. Two types of bronzing have been recognized (78): one appears 1 to 2 weeks after transplanting and is associated with sandy soils adjacent to lateritic highland; the other appears 1 to 2 months after transplanting, especially soon after top-dressing with ammonium sulfate, and is associated with peaty or boggy soils. According to Ponnamperuma *et al* (*86, 87*), incidence of bronzing is associated with high ferrous iron concentrations in the soil solution.

The brown spots on leaves appear when the roots or cut leaves are placed in a strong solution of ferrous iron (*78, 122, 136*). Accumulation of absorbed iron is found in the brown spotted sites (*122*).

From this evidence there is little doubt that symptoms of bronzing can be induced by an unusual accumulation and localization of iron in the leaves. Opinions differ, however, as to the direct cause of bronzing. Root damage caused by hydrogen sulfide has been suggested as a possible primary cause (*23, 136*), and there is little doubt that this could aggravate iron toxicity by destroying the oxidizing power of the roots under certain circumstances (*126*).

As distinct from the iron toxicity theory, there is an opinion that bronzing is caused by the combined effect of high aluminum and low calcium in the soil (*78, 79*). There is still another report (*27*) which maintains that lack of oxygen, formation of hydrogen sulfide, and accumulation of ferrous iron cannot cause physiological diseases of rice.

As remedy, liming is found very effective. This increases pH and is accompanied by decreased ferrous iron concentrations in the soil solution. Application of compost is also very effective in reducing the incidence of bronzing.

COLOMBIA

Espiga Erecta (*46*)

In Espiga Erecta (straighthead) the panicles of affected plants remain erect at maturity because of insufficient development of grains. Usually the panicles are completely sterile. The glumes (hulls) are twisted in a semicircular form (the shape of a half-moon) and ordinarily one of the glumes of each flower disappears. In extreme cases, the number of panicles is reduced and the last leaf emerges in an incomplete form. Generally, one or two shoots emerge from the inferior nodes. The roots of affected plants are coarse, shallow, and sparingly branched in contrast to normal plants with well-developed roots.

Espiga Erecta is often severe in slightly sandy-clayey soils that are not drained or allowed to dry completely after harvest. Usually it prevails in virgin lands or in areas where rice has not been grown for several years.

The cause of Espiga Erecta is not yet known, but it may be unfavorable soil conditions aggravated by prolonged flooding. It is generally presumed that the disorder is physiological. Use of resistant varieties and drainage before flowering are two known control measures.

HUNGARY

Brusone (*130, 131, 150*)

Brusone usually refers to damage caused by *Piricularia oryza*. The most obvious symptom is brown discoloration of the tissues of lower nodes. The roots of plants showing luxuriant development are completely killed. The leaves have large but few fungal spots (*Piricularia oryzae*). Negatively geotropic roots frequently develop from nodes that are above the surface of the water. Neck rot is sometimes observed. The panicles are always empty.

Opinion is divided on whether brusone is simply blast disease or a disorder related to soil conditions. The incidence of brusone appears to be closely related to soil and weather conditions. It occurs on heavy acid soils and on heavy soils with high contents of organic matter and nitrogen at lower elevations. Brusone causes heavy damage when a warm summer period is rapidly followed by a cool and cloudy period lasting for 8 to 10 days.

The suspected direct causes of brusone: blast disease, toxicity of hydrogen sulfide, and excessive nitrogen nutrition. Excessive nitrogen favors a rapid development of *Piricularia oryzae*, which leads to a decreased root-shoot ratio and consequently causes physiological drought.

Considering its symptoms and the conditions under which it occurs, brusone appears to be akin to "Hie-imochi," a kind of blast disease occurring where crops are irrigated with cold water in northern Japan.

INDIA

Khaira disease (*66, 67, 68*)

The disease appears in a severe form in the Tarai region of Uttar Pradesh. About 2 weeks after transplanting, the disease starts appearing in low-lying and more or less circular patches in the field. Over-all growth of the plants is retarded. Brownish-red (rusty) discoloration appears on the surface of the outer leaves. The tips of many leaves become dry and a yellowing followed by rusty discoloration proceeds downwards from the tips along the margins of the leaves. The root system develops poorly. Many outer spongy roots are dead and the root system in general shows brown to dirty-black discoloration. Generally, 6 weeks after transplanting, the diseased plants in the field start producing new tillers and recover to some extent. Such plants, however, produce at the most three to four poorly developed panicles.

It was found that the incidence of the disease is associated with higher soil pH. For example, 2 to 4 weeks after transplanting, the soil pH in areas with diseased plants was consistently between 7.8 to 8.2, while in areas with healthy plants, it was 7.0 to 7.3. Combined application of organic matter (freshly chopped dhaincha) and superphosphate alleviated the disease to a considerable extent. This was considered to be due to a lowering effect on pH of the applied materials. Later it was demonstrated that a foliar application of zinc sulfate could control the disease.

Bronzing (*94*)

Three different kinds of disorders were reported under the name of bronzing. The following symptoms were recorded 45 days after transplanting:

Waterlogged latosol soil. The leaf tip becomes purple. The color spreads along the margin, the midrib region remaining green for some time. Blackish brown spots appear on the upper halves of the margin of older leaves. As the disease progresses, the affected leaves dry up giving the rice clump a scorched appearance. Toward the time of flowering, the upper leaves become shorter and the lower ones dry up to a dirty-yellow color with brown spots and streaks on the surface. Discoloration and brown spots and streaks appear on all aerial parts, including the leaf sheath, flag leaf, and some grains. The proportion of sterile florets in affected plants is greater than in healthy ones. Roots of affected plants lack the dense mat of fine secondary rootlets and are greyish white or dark reddish brown. Toward the period of initiation of panicle primordia and of flowering, diseased roots emit a foul smell when uprooted. The soil has a low pH (4.5 to 5.0) and is loamy sand in texture. Affected plants have low phosphorus, potassium, and manganese contents, but a high iron content. The disorder is considered to be due to iron toxicity. Liming, application of phosphorus and potassium, and drainage can correct it.

Dahal land (*swampy lowland soil*). The upper leaves become progressively shorter; lower leaves dry up to a dirty-yellow color with brown spots on the surface. The roots of affected plants are pale white and mingled with black or rotten ones. The soil pH is around 6.0 and the texture, loamy sand. Application of upland lateritic soil alleviated the disorder. The main cause is considered to be hydrogen sulfide injury.

Bahal land (*bottom land between two slopes*). The leaf tip turns yellow brown and appears chlorotic. The roots of affected plants are coarse and sparse, become blackened and rotten. The plants can be pulled out easily. The soil is about neutral in reaction and sandy clay loam in texture. The chemical composition of affected plants is characterized by high manganese content and a low iron-manganese ratio. Their phosphorus and potassium contents are also low. The cause of this disorder was considered to be manganese toxicity.

Yellowing (*29*)

An obscure disease of rice has been reported from Bengal and Bihar. The normal color changes to brownish and, sometimes, orange-red followed by withering, giving the appearance of almost dead plants. The affected plants can be more easily uprooted and the roots, although not dead, appear to be in a dying phase and are dirty-black to brown. The disease occurs at two stages: during tillering and during flowering. The disease starts in circular patches and at times in a straight line adjoining bunds. The surrounding crop is healthy and often vigorous. No pathogens could be detected.

Occasionally, higher concentrations of nitrite or ferrous iron were detected in the root zone of affected plants than in the roots of healthy plants. The cause of the disorder remains obscure.

Application of ammonium sulfate and a mixture of trace elements, such as copper, zinc, boron, and manganese, did not correct the disease, but application of phosphate combined with drainage alleviated it to some extent.

INDONESIA

Mentek (*80, 93, 132*)

The word "mentek" in Indonesia literally means midget. One hundred years ago, mentek was believed to be caused by insects that were difficult to observe since they were active at night and hid in the soil during daytime. The Javanese ascribe the disease to invisible midgets (mentek). The name "mentek" is used in Central and West Java mainly to indicate a disease characterized by a reddish to brownish, sometimes yellowish, discoloration of the leaves, together with the inability of the plants to produce normal panicles. Many local names appear to designate the same disease as mentek, for instance, "omo merah" (red disease), "omo abang," "omo tepak," and "omo bambang." Thus, the term "the mentek" is considered to be a group name for diseases occurring in Indonesia and characterized mainly by reddish discoloration of leaves and stunted growth.

The disease has been studied since 1859 and, until recently, has been one of the most destructive diseases of rice in Indonesia. At present mentek is not a serious problem because resistant varieties such as Bengawan are grown extensively. The first suspected cause of mentek was nematode injury. Then it was growth disturbances resulting from physiological causes. Subsequently, the nematode theory was revived.

Recently, it has been proved that tungro disease is established in Indonesia. Since the symptoms of mentek are almost identical with those of Penyakit Merah, which has been proved to be a virus disease, and since varieties resistant to mentek, such as Peta, Bengawan, Intan, and Mas, are also resistant to tungro, it seems reasonable to regard most mentek, if not all, as being caused by a virus, possibly similar to Penyakit Merah or tungro.

JAPAN

Akiochi (*9, 11, 15, 19, 30, 32, 45, 55, 56, 57, 58, 59, 60, 61, 62, 71, 75, 98, 99, 103, 104, 112, 113, 142, 146*)

Aki-ochi literally means autumn-decline. The plant has vigorous or normal growth at earlier stages but begins to decline gradually just before or after heading. Its lower leaves die first, and the shoot and panicle become discolored with a dirty stain. The grain yield is lower than would be expected from the plant's early appearance.

Affected plants are characterized by: (a) lower percentage of effective (panicle-bearing) tillers; (b) shorter culms and panicles; (c) fewer spikelets per panicle and higher percentages of unfilled grains; (d) lower grain-straw ratio; (e) appearance of dark-brown spots on grains; (f) smaller grain weight; (g) earlier death of lower leaves; (h) a root that is pale white or black and often rotten; and (i) *Helminthosporium* leaf spots.

Akiochi has been known for a long time in southern Japan. The replacement of organic manures with inorganic fertilizers is believed to accentuate the problem. The disease is closely related to soil types and climate. It occurs mainly on sandy, well-drained, degraded soils derived from granite or similar rocks and on ill-drained organic soils. The degraded soil is characterized by eluviation of iron, manganese, phosphorus, potassium, magnesium, etc., from the surface to a lower horizon. Chemical analysis of degraded soils shows low free iron, low reducible manganese, low available silica, and low cation exchange capacity. Affected plants are characterized by very low silica and low potassium, but rather high iron content. About 20 percent of the total rice acreage in Japan was once estimated to be affected by Akiochi. The disease was commonly found in southwestern Japan and high temperatures in summer were thought to aggravate it.

The main causes of Akiochi are toxicity of hydrogen sulfide produced under reductive conditions; deficiencies of silica, magnesium, and bases in general; and deficiencies of nitrogen and potassium at later stages of growth. The mode of action of hydrogen sulfide has been thoroughly studied (*60, 61, 62, 71*). Hydrogen sulfide is a respiratory inhibitor. Since nutrient uptake requires energy, which is supplied by respiration, it is impaired by hydrogen sulfide in the soil.

The biological role of silicon in the rice plant has also been the subject of extensive studies in Japan (*32, 45, 75, 142, 146*). Increased absorption of silicon increases resistance to some fungus diseases and pests. It also maintains more erect leaves which are important in maintaining adequate light conditions in a rice population. Where silicon content is extremely low, increased absorption of silicon raises the plant's resistance to high osmotic pressures. In degraded soils, ammonium or potassium are readily available to and absorbed by the rice plant at early stages of growth but these cations are readily leached and lost so that the rice plant becomes deficient in these nutrients at later stages.

The remedial measures suggested for the prevention of Akiochi: (a) avoiding the use of sulfate-containing fertilizers; (b) incorporation of iron-rich hill soil; (c) application of furnace slag which contains weak acid-soluble silica, calcium, magnesium, and manganese; (d) adoption of resistant varieties; and (e) draining in mid-summer, to restore the oxidative conditions of the soil. Nowadays, Akiochi has been almost overcome.

Akagare (*10, 12, 13, 14, 16, 17, 18, 19, 50, 74, 102, 106, 107, 112, 113, 137, 138*)

Aka-gare literally means red-withering. It appears 2 or 3 weeks after transplanting and the main symptom is the appearance of reddish-brown spots on the older leaves of the plant. Akagare is classified, according to symptoms and causes, into three major types.

Akagare Type I: The leaves first turn dark green, and then small reddish-brown spots appear near the tips of older leaves. The spots spread over the leaves, which die, starting from the tips. The roots turn light brown (in sandy soils) or dark reddish-brown (in muck or boggy soils). In many cases, blackened or rotten roots occur. This type occurs in ill-drained soils particularly muck or boggy soils. Since it can be prevented by the application of potassium, it is considered to be an expression of potassium deficiency.

Akagare Type II: First, the midribs of the leaf turn yellow, then reddish-brown spots appear around the discolored part until the whole leaf becomes reddish brown. In acute cases, reddish-brown spots often appear without the previous yellow discoloration. The roots of affected plants are reddish-brown or dark reddish-brown, often mingled with black or rotten ones.

This type occurs mostly in ill-drained muck or boggy soils and cannot be prevented by the mere application of potassium. The main causes are considered to be toxicities of organic acids, such as butyric and acetic acids, soluble iron, and hydrogen sulfide associated with potassium deficiency.

Akagare Type III: Small brown spots appear on the tips of older leaves. The spots subsequently spread over the surface, giving the leaves a yellowish-brown or brown discoloration. The leaves finally die. From a distance, affected plants resemble those heavily attacked by leaf blast.

This type occurs in reddish heavy clay loam and in Ando soils newly converted from upland soils to lowland rice soils. Such soils are extremely deficient in phosphorus and are often acidic. The incidence of the disorder is most severe in the first year of the conversion to paddy fields and lessens with the years. It disappears after a few years of rice cropping. The main cause of this type was considered to be certain organic compounds.

The most recent reports, however, indicate that Akagare Type III is caused by excess iodine*.

Aogare (*19, 105, 147, 148, 149*)

The literal meaning of Ao-gare is green-withering. A sudden withering takes place at about 20 days or

*See the articles "Radio-iodine uptake by plant from soil with special reference to lowland rice" by K. Tensho and Ko-Ling Yoh, and "Iodine toxicity as a cause of 'Reclamation Akagare' disease of rice plant" by I. Watanabe and K. Tensho Both articles are in press in Soil Sci. Plant Nutr.

more after heading. The plant withers first at the upper leaves, then in its entirety in 1 or 2 days. The disorder is accelerated by drainage after heading. Typhoon, dry wind, and cool air also accelerate its occurrence.

Aogare broke out in the southwestern part of Japan in 1955. The disorder occurs in well-drained sandy soils. Affected plants are characterized by low potassium and high nitrogen content, hence by low potassium-nitrogen ratio, and by low carbohydrate content. The physiological cause of Aogare is apparently an imbalance between absorption and transpiration of water, which in turn may result from imbalanced potassium and nitrogen nutrition.

Hideri-Aodachi (*5, 6, 9, 19*)

Hideri-Aodachi literally means "green straighthead due to drought in sunny weather." The disorder is characterized by an extreme sterility associated with deformed flowers with beak-shaped lemmas and degenerated paleas. The disorder occurs when an ill-drained peaty or boggy paddy field with stagnant water throughout the year dries up during a long spell of dry weather.

The disorder never occurs unless the soil dries up to some extent. It occurs when a soil is dried and kept at a moisture content of 50 to 70 percent of the maximum water-holding capacity without causing leaves to wilt.

The disorder is suspected to be related to a high content of decomposable organic matter or a low content of free iron.

Straighthead (*19, 36, 51*)

The main symptoms of straighthead are dark-green stiff leaves and stems, stunted growth, and abnormalities of sexual organs such as the thin development of rachis, branchis, and flowers in a panicle, and sterility of flowers.

The disorder is observed in paddy fields that have been upland fields until about 1 to 3 years earlier.

The incidence of the disorder seems related to reductive conditions of the soil, and some unknown organic substances are suspected to be the causative factors. It is prevented by draining the field 5 to 10 days before panicle initiation stage.

KOREA

Akiochi (*83, 129*)

A physiological disorder similar to Akiochi in Japan has been reported to be a serious problem in Korea. The disorder is accompanied by *Helminthosporium* leaf spot. In some cases, application of calcium silicate alleviates the condition to a considerable extent. Affected plants are high in sulfur and iron but low in potassium, magnesium, manganese, and silica.

Most Akiochi soils are derived from granite or peat. They are generally low in pH and cation exchange capacity. A pot experiment has demonstrated that with impeded drainage, an Akiochi soil can induce iron toxicity in rice (83).

MALAYSIA

Penyakit Merah (*53, 80, 81, 112, 113*)

Penyakit Merah literally means red disease. It was first recorded in 1938 (*53*). Two types of symptoms have been recognized (*53, 112*). In the brown-spot type, small, dark-brown spots appear near the tips of the older leaves. In the yellowing type, the tips of the older leaves turn yellow, and this color progresses down the lamina, leaving the midrib green. Later, the yellow areas and midrib turn orange.

Penyakit Merah has been extensively studied from the viewpoint of plant nutrition. The brown-spot type was considered to be caused by nitrogen deficiency and the yellowing type by manganese deficiency (*53*). Injury by hydrogen sulfide, organic acids, and nematodes was also examined.

Recently, it was shown that most Penyakit Merah, if not all, is caused by a virus (*80, 81*).

PAKISTAN

Pansuk (*47, 48, 112, 113*)

The symptom of Pansuk is reddish-yellow discoloration of the leaves, starting from the tips. The disease is associated with stagnant water and can be partially cured by drainage. Application of fertilizers such as ammonium sulfate or cow dung may sometimes help in bringing about partial recovery. The scented varieties appear to be free from the disease while non-scented varieties are affected to varying degrees.

The chemical composition of affected plants is reported as low potassium content and unbalanced potassium-nitrogen and iron-manganese ratios (*48*). The data, however, do not suggest any possibility of nutrient deficiencies or excesses.

PORTUGAL

Branca (*21*)

Branca is a physiological disease of paddy rice in Portugal, characterized by a high level of sterility. Frequently, the only apparent symptom is the failure to set grain while the vegetative growth appears normal. A wide range of flowering abnormalities is observed: deficiently segmented panicles, reduced number of flowers per panicle, distorted flumelulles, and various kinds of pistil and stamina malformations. In extreme cases, the plants remain dwarfed, with very short internodes.

The leaves are yellowish, dried, and rolled up at the tips. The head is frequently reduced to the basal rachis Branca has been known for a long time in Portugal and is believed to be a non-pathogenic disease. Copper deficiency, either due to absolute lack of copper or its unavailability under reductive conditions in the soil, is suspected to be responsible for the disorder. It can be partially prevented by drying the paddy field for 1 to 2 weeks some time before heading. Application of copper sulfate is effective.

THAILAND

A disorder (*112*, *113*) is found on the Ongkarak clays of the Bangkok plain. These clays are very acid, ranging in pH from 3.4 to 4.5.

Affected plants are stunted and in severe cases they die. Those that remain stunted either produce few grains or none at all. The plants usually do not produce any tillers. The disorder is suspected to be due to aluminum toxicity. The application of lime alleviates the disorder to some degree. The area affected is about one-third of the whole Bangkok plain.

TAIWAN

Suffocating disease (*23, 25, 26, 114*)

In Ilang Prefecture, northeastern part of Taiwan, a disorder called chin-seng-tien has been known for many years. The literal meaning of chin-seng-tien is cool acid paddy. It is characterized by poor growth, appearance of brown spots on leaves, and is very frequently accompanied by *Helminthosporium* leaf spot. Affected fields have very poor drainage and a high water table. In 1959, a new disease broke out in Pingtung Prefecture, southern part of Taiwan. The symptoms of the disease are leaf yellowing, stunted growth, and root rot. Ponlai varieties are more susceptible than the native indica varieties.

These two diseases were first thought to have common causes—poor soil drainage, insufficient supply of oxygen, inhibition of root respiration, production of harmful reducing substances, and probably potassium deficiency. Consequently, it was proposed that both diseases be called suffocating disease. Later, the disease occurring in southern and central Taiwan was found to be caused by a virus, and was called transitory yellowing. Judged from the above information, it is likely that the disorder found in the Ilang area is related to a soil problem and that the one occurring in the southern and central part of Taiwan is at least partly caused by a virus. Thus, it is inadvisable to continue to use the term suffocating disease to designate the disorders found in Taiwan in general.

U.S.A.

Straighthead (*4, 24, 28, 128*)

Straighthead is one of the most destructive diseases of rice in southern U.S.A. The name of the disorder is derived from the most obvious symptom: failure to produce filled grain, resulting in an erect panicle at maturity. The leaves and culms of affected plants are usually green and rigid. The florets are frequently deformed and usually described as parrot beak glume. Affected plants usually have relatively large, shallow roots with few branches and root hairs, as distinguished from the fine, well-branched root system which characterizes a healthy plant. Since no parasitic organism has been associated with the disease, it is generally regarded as non-parasitic.

The soil at Eagle Lake, Texas, where straighthead is commonly observed, is an alkaline fine sandy loam.

Straighthead can usually be controlled by draining the field before the panicle develops, and allowing the soil to dry. This method has been practiced successfully for a number of years. Recently, Evatt and Atkins (*28*) reported that application of a mixture of boron, zinc, copper, and iron alleviated the incidence of straighthead and resulted in a statistically significant yield increase.

Varietal difference in resistance to straighthead is quite obvious. Among the popular Texas varieties, Bluebonnet, Bluebonnet 50, and Texas Patna are resistant or moderately so, whereas Century Patna 231, Improved Bluebonnet, Rexoro, Sunbonnet, TP49, and Zenith are susceptible.

At present, the exact cause of straighthead is not known.

Alkali disease (*54, 85*)

Severe chlorosis occurs on water-sown rice in alkali areas of California. Chlorosis appears as soon as the first true leaves are formed. The chlorosis, which is uniform over the entire plant, becomes increasingly severe with time. Eventually, irregular dark necrotic spots develop on the leaves which are structurally weak and float on the water. Affected plants usually die some 4 to 6 weeks after planting and subsequently completely disintegrate in the water. Rice production is usually a complete failure, but occasionally a few scattered plants survive. Soils on which rice responds to iron compounds have alkaline pH values and a high percentage of exchangeable sodium. This is a case of iron deficiency of paddy rice. Application of ferric sulfate is very effective in curing the chlorosis.

A similar chlorosis also occurs on alkaline soils at Grand Prairie, Arkansas. The soil has an excess of lime and a pH of 7 to 8. Application of ferric sulfate or sulfuric acid corrects the chlorosis.

VIETNAM

Acid sulfate soils (*64, 89, 123*)

Acid sulfate soils usually develop in the tidal mangrove swamps and in the swamps on the seaward side of river deltas. Rice suffers from a disorder and is often a complete failure. In Vietnam, more than 1 million hectares of land have this type of soil.

The soil has a high sulfur content, and when dry, becomes very acidic due to the formation of ferric sulfate and sulfuric acid from pyrites. Occasionally pH values of approximately 1 to 2 have been observed in oxidized horizons of the soil. Under reductive conditions after flooding, pH values may rise gradually, eventually approaching neutrality due to reduction of sulfates to sulfides.

The main causes of the disorder on acid sulfate soils have been considered to be the soil acidity itself; toxicity of iron and aluminum, and possibly manganese; low fertility level, mainly phosphorus deficiency; and poor physical soil conditions (*64*).

Studies on the soil solution of acid sulfate soils (*123*), however, indicate that under upland conditions aluminum toxicity can be a causative factor of poor growth but under flooded conditions iron toxicity, combined with phosphorus deficiency, is a major cause of the trouble. Rice plants grown on acid sulfate soils show typical iron toxicity symptoms. It has also been demonstrated that manganese toxicity is unlikely.

Although there is no simple practical solution to the problem of acid sulfate soils, three measures have been suggested (*64*):

- Preventing drainage and subsequent aeration and acidification. This is a general practice in the Mekong delta. In this way the development of sulfuric acid is prevented.
- Promoting drainage (especially by ridging the land). Acidification will proceed rapidly and, if the rainfall is high enough, the acid and toxic products will be gradually leached; the topsoil will then become moderately acid (pH 4.0 to 4.5) and non-toxic.
- By liming, the acid which is being formed will be neutralized. In principle, liming should be combined with careful and progressive drainage, thus gradually releasing and neutralizing the potential acidity. Where such a combined system has been applied on medium acid sulfate soils, good results have been obtained.

In a greenhouse experiment, it was shown that application of manganese dioxide can be an effective remedy for acid sulfate soils (*89*). Based on extensive studies of the chemistry of a flooded acid sulfate soil, provisional reclamation measures have been proposed (*69*): leaching the soil with fresh water to lower the concentration of salts, chiefly sulfates; liming aerobic soil to pH 4.7 to prevent aluminum toxicity and to decrease iron toxicity; applying manganese dioxide to counteract iron toxicity; adding ferric oxide (red earth) to counteract hydrogen sulfide toxicity in soils low in active iron, and maintaining a continuous flood after these combined treatments.

How the survey was done

DEFINITION

"Nutritional disorder" is defined here as any abnormality of the rice plant caused by a deficiency of any essential element, any toxicity caused by a high level of any substance or ion in the soil, and any retarded growth due to a high osmotic pressure of the soil solution.

Nitrogen deficiency is common in tropical Asia and nitrogen excess also sometimes causes decreased grain yield. However, these problems have been excluded from the survey because they have been discussed elsewhere (*118, 124*).

Disorders caused by the combined effects of deficiencies of some elements and toxicity of certain substances are common, thus complicating many problems.

SCOPE AND METHOD OF SURVEY

It was intended to embrace all Asian rice-growing countries, but for various reasons the survey was restricted to South Korea, Japan, Taiwan, Philippines, Indonesia (West Java only), Thailand, Malaysia, India, West Pakistan, and Ceylon. The area involved was so vast that the only practical approach was to select a variety of typical situations for examination. In making these selections, the following soil and physiographic features were important.

Soils developed with good drainage

In Asia, rice is extensively grown on alluvial soils in river deltas under conditions of high precipitation. In such situations, water supply is assured even without proper irrigation facilities. The parent materials of the soils in alluvial areas are derived from the surrounding elevated areas. Thus, the soils are closely related to those on the adjoining high land. With development of irrigation facilities, rice growing is expanding into areas with elevated topography where the soils are well-drained and undergo either podsolic or lateritic weathering depending upon climatic conditions. Various elements including potassium, calcium, magnesium, and phosphorus are leached from the soil and pH becomes low. In the case of podsolic soils, iron and aluminum are leached from the top soil. On the other hand, silica is leached from lateritic soils which become relatively high in iron and aluminum. The amount of these elements is of course affected by parent materials, climate, and soil age. On highly weathered soils, deficiencies of phosphorus, potassium, magnesium, and manganese and, in lateritic soils, iron toxicity may occur.

Soils developed under poor drainage

In ill-drained areas of depressed topography, peaty soils develop if the site is continuously wet. Alkaline or saline soils develop if there is an annual dry season.

Peaty soils are often low in various elements (phosphorus, potassium, etc.); they also have low pH and a high content of organic substances. Because of ease of irrigation, rice is one of the most likely crops to be grown after reclamation. The abundance of organic substances often causes problems but the areas can be made productive with proper management.

On alkaline or saline soils in dry areas, attempts have been made to grow rice when irrigation water becomes available. Alkalinity and salinity pose problems. One of the major ones is the susceptibility of the rice plant to iron chlorosis at high pH. Availability of certain micro-elements such as zinc, is often low at high pH and this also causes problems.

Soils in coastal areas

There are large areas of acid sulfate soils on coastal plains and in coastal areas reclaimed by poldering. These areas are suitable for rice cultivation because of their suitable topography for irrigation and the resistance of the rice plant to acidity. Excessive iron or aluminum, and a low supply of nutrients such as phosphorus and potassium are the problems. Sulfide is a further factor causing disorders.

Salinity is often a problem in coastal areas, especially when the tidal fluctuation of sea level is large.

Soils developed from particular parent materials

Soils inherit various characters from their parent materials. For example, soils derived from granite are often responsible for "Akiochi" due to coarse texture and low levels of iron, manganese, and other elements. Soils developed from limestone are high in calcium, and various abnormalities may occur due to high pH. They are sometimes low in potassium, and rice may suffer from a deficiency. Soils from basaltic material may be deficient in available phosphorus at a certain stage of laterization. Soils developed from volcanic ash, especially the Ando soils in Japan, are frequently high in active aluminum which by fixing phosphorus may result in a deficiency of this element.

Some soils are derived from materials high in toxic elements such as nickel or copper, or low in other elements.

During the survey, efforts were made to traverse rice areas in Asia as widely as possible during the rice season, seeking fields where plants were suffering from abnormalities considered to be due to soil rather than other factors. Information was also sought in the literature and by personal contact.

When nutritional disorders were suspected, symptoms of the abnormal plants were recorded and samples of plants and soils were taken. The plant samples were analyzed for various elements. The soil samples were dried and ground and used for determination of pH, organic matter, cation exchange capacity, exchangeable cations, phosphorus absorption coefficient, available phosphorus, active iron, easily reducible manganese, etc.

Simple bottle or standard pot experiments were conducted with problem soils to supplement the observations and analyses of the plant and soil samples.

DIAGNOSTIC TECHNIQUE

Diagnosing a disorder is both important and difficult. There is no single method whereby an accurate diagnosis can be made of a nutritional disorder, and a combination of two or more techniques is more likely to be successful. Much experience is required before one can make reliable diagnoses, and it is important to realize that they can be made with confidence only when deficiencies or toxicities are extreme.

Symptoms of nutritional disorders frequently resemble those of pathogenic diseases, especially virus diseases, and it is necessary to consult plant pathologists to avoid confusion. For convenience, visible symptoms of the main virus diseases occurring in Asia are described in the Appendix.

To acquire the necessary experience it is advisable to become familiar with the typical symptoms of deficiencies or toxicities of the various elements or substances under water culture conditions, and to accumulate analytical data on affected plants. On the basis of such experience one can make an adequate diagnosis by visible symptoms and plant tissue analysis.

Analytical data on soils also give valuable information as to whether or not a suspected nutritional disorder is possible or likely.

Visible indications—deficiency symptoms

Nitrogen: Plants are stunted with a limited number of tillers. Leaves are narrow and short, erect and yellowish-green, except young leaves which are greener. Old leaves die when light straw colored.

Phosphorus: Plants are stunted with a limited number of tillers. Leaves are narrow and short, erect and dirty dark green. Young leaves are healthier than the others and old leaves die when brown colored. Reddish or purplish color may develop on leaves if the variety has a tendency to produce anthocyanin pigment.

Potassium: Plants are stunted, but tillering is only slightly reduced. Leaves are short, droopy, and dark green. On lower leaves, yellowing takes place at the interveins, starting from the tip, and eventually these dry to a light-brown color. Sometimes brown spots may develop on dark-green leaves.

Sulfur: The symptoms are very similar to those of nitrogen deficiency, and it is almost impossible to distinguish between them by visible symptoms alone.

Calcium: General appearance of the plant is little affected except for acute deficiency. The tip of the upper growing leaves becomes white, rolled, and curled. In an extreme case, the plant is stunted and the growing point dies.

Magnesium: With moderate deficiency, height and tiller number are little affected. Leaves are wavy and droopy due to expansion of the angle between the leaf blade and the leaf sheath. Interveinal chlorosis occurs on lower leaves. The chlorosis is characterized by an orangish-yellow color.

Iron: Entire leaves become chlorotic and then whitish. If iron supply is cut suddenly, the newly emerging leaf at this time is subjected to chlorosis.

Manganese: Plants are stunted with normal tiller number. Interveinal chlorosis appears on leaves. The chlorotic streaks spread downward from the tip to the base of leaves, and later become dark brown and necrotic. The newly emerging leaves become short, narrow, and light green.

Zinc: The mid-ribs of the younger leaves, especially the base, become chlorotic. The more general symptoms are the appearance of brown blotches and streaks in lower leaves, followed by stunted growth. Tillering may continue. The size of the leaf blade is reduced, but that of the leaf sheath is little affected. In the field, uneven growth and delayed maturing are characteristics of zinc deficiency.

Boron: Plant height is reduced. The tips of emerging leaves become white and rolled as in the case of calcium deficiency. The growing point may die in a severe case, but new tillers continue to be produced.

Copper: The leaves appear bluish-green, and then become chlorotic near the tips. The chlorosis develops downward along both sides of the mid-rib, followed by dark-brown necrosis of the tips. The new, emerging leaves fail to unroll. They maintain a needle-like appearance for the entire leaf or, occasionally, half the leaf, with the basal end developing normally.

Low silicon content: Leaves become soft and droopy.

Visible indications—toxicity symptoms

Iron: First, tiny brown spots appear on lower leaves, starting from the tips and spreading toward the bases. Generally, these spots are combined on interveins. Leaf color usually remains green. In a severe case, the entire leaves look purplish brown.

Manganese: The plant is stunted and tillering is often limited. Brown spots develop on the veins of the leaf blade and of the leaf sheath, especially on lower leaves.

Boron: Chlorosis takes place at the tips of the older leaves, especially along the margins, followed by the appearance of large, dark-brown elliptical spots in the affected parts which ultimately turn brown and dry up.

Aluminum: Interveinal chlorosis in orangish-yellow color. In serious cases the chlorotic portion may become necrotic.

High salt injury: Stunted growth and reduced tillering. The tips of leaves become whitish and, frequently, some parts of the leaves become chlorotic.

Lower and upper critical contents of elements in the rice plant grown in water culture

Information on the critical contents of elements in the rice plant below which deficiency symptoms may develop, or above which toxicity symptoms may become visible, allows diagnosis of abnormal rice plants growing in the field by chemical analysis of the plants.

Table 1 is a tentative list of these critical contents of various elements. These figures are subject to modification according to the criteria by which the disorders are defined, status of other elements or substances in the soil, and growth stages of the plant, varieties, climatic conditions, etc. The critical content obtained from the greenhouse study is sometimes too high, and is not applicable to the field crop (*39*). Changes during growth of availability in the growth media of the element in question also have a strong influence on the critical content.

For these reasons, the figures in Table 1 should be used only as a guide for diagnosis. If the content of an element in plants suffering from a disorder is below the critical content listed in Table 1, it is possible that deficiency of the element is the cause. Also, if the content is far above the toxicity critical content, toxicity of the element may be suspected.

Table 1. Deficiency and toxicity critical contents of various elements in the rice plant*.

Element	Deficiency (D) or toxicity (T)	Critical Content	Plant part analyzed	Growth stage**	Citation
N	D	2.5%	Leaf blade	Til	38
P	D	0.1%	Leaf blade	Til	38
	T	1.0%	Straw	Mat	40
K	D	1.0%	Straw	Mat	41
	D	1.0%	Leaf blade	Til	38
Ca	D	0.15%	Straw	Mat	42
Mg	D	0.10%	Straw	Mat	42
S	D	0.10%	Straw	Mat	42
Si	D	5.0%	Straw	Mat	146
Fe	D	70 ppm	Leaf blade	Til	111
	T	300 ppm	Leaf blade	Til	122
Zn	D	10 ppm	Shoot	Til	144
	T	1,500 ppm	Straw	Mat	44
Mn	D	20 ppm	Shoot	Til	119
	T	> 2,500 ppm	Shoot	Til	119
B	D	3.4 ppm	Straw	Mat	44
	T	100 ppm	Straw	Mat	44
Cu	D	< 6 ppm	Straw	Mat	49
	T	30 ppm	Straw	Mat	43
Al	T	300 ppm	Shoot	Til	121

* Figures for critical contents collected from references cited but adjusted to round figures.
** Mat—maturity; Til—tillering

The surveys

SOUTH KOREA

South Korea* occupies the southern half of the Korean peninsula and is in the temperate zone. At the time of the field inspection, rice plants were at a stage of from about 1 month before panicle primordium initiation to booting, depending upon location and date of planting. Samples were taken at 14 sites as shown in Figure 1 and Table 2. Analytical data of plants are given in Table 3 and those of soils in Table 4. Parent materials of the soils in the area covered by the field trip are mostly granite or granitic gneiss, except in the Ulson area where the parent material is shale (Site 13). Upland soils are whitish in color at many sites and reddish at others. Though the colors are different, the parent material seems to be the same in these areas. Red color may not indicate the level of iron in the soil. Mountains or hills are thinly covered with pine trees, indicating a poor nutrient supply in soils.

Soils of the rice fields are mostly river alluvium but, in some areas, they are derived from marine alluvium (Sites 1, 5, 11, 12, 13). They are generally sandy or silty, but some (Sites 12, 13) are rather clayey with poor permeability. The pH of the wet soils is about 6.0 to 6.5, but acidic, 4.5 to 5.0, when dry. One acid sulfate soil (Site 12) has a very low pH.

Cation exchange capacity of the soils is extremely low, ranging from 4 to 8 meq/100 g soil, except Site 12 which has 16 meq/100 g soil. Exchangeable cations are generally very low. Exchangeable calcium is low, ranging from 1.4 to 3.6 meq/100 g soil; exchangeable magnesium is low except soils of marine alluvium (Sites 1, 5, 12); exchangeable potassium is extremely low except Site 12; and exchangeable sodium is also low except the soils with marine influence (Sites 1, 5, 11, 12).

Phosphorus absorption coefficient of the soils is generally low except in Site 12.

Active iron content of these soils is not particularly low. In some soils (Sites 4, 6, 9), however, there is a possibility of free hydrogen sulfide if sulfate fertilizers are applied and the soils kept flooded.

Generally speaking, soil features are similar to those on which "Akiochi" occurs in the Chugoku district of Japan and where "bronzing" is frequent in the wet zone of Ceylon.

In many areas "Akiochi" was very serious. *Helminthosporium* infestation was just starting at the time of our visit, and was expected to become much more serious as the plants aged. This disorder of rice seems to

*Visited in July and August 1967.

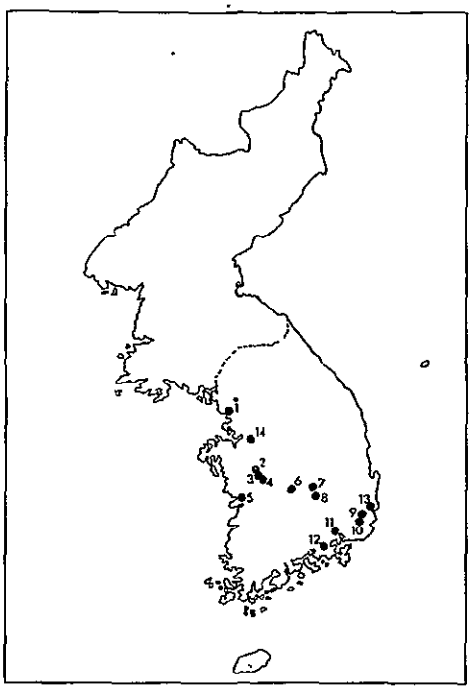

Fig 1. Survey sites in Korea.

be widespread in South Korea and is the greatest problem.

At several sites "Akagare" was serious. The symptoms were identical with those of "Akagare Type I," although the other type of Akagare occurs where drainage is extremely poor or soil pH is very low.

"Akiochi"

Rice plants affected by "Akiochi" were severely infested by *Helminthosporium* leaf spots. Frequently, blast spot was also noticed on the same plants. It is generally believed that when plants are well supplied with nutrients they suffer from blast, and when they are suffering from malnutrition *Helminthosporium* leaf spots appear. However, in "Akiochi" areas in Korea both diseases occur on the same plant.

The plants in the area were generally low in potassium and silica. Nitrogen content was also rather low. Iron content was high in all cases. Some plants were rather low in calcium or magnesium.

These data indicate that the plants were poorly supplied with many nutrients. Judging from the black roots of some sample plants, free hydrogen sulfide in the soil could have been fairly high and could have inhibited nutrient uptake.

Blast in lower leaves indicated that the nitrogen content of the plant was high at early stages of growth due to nitrogen fertilizer application. However, at the time of sampling, the nitrogen content was rather low, suggesting that it fluctuates during growth, largely due to the low cation exchange capacity of the soils. When nitrogen fertilizers are applied, the nitrogen content

Table 2. Sampling sites in Korea.

Site no.	Site	Note
1	Juan, Buchun, Gyeonggi	Many Helminthosporium leaf spots. Black roots.
2	Kangae, Cheong Weon, Chung Buk	K deficiency. Helminthosporium leaf spot. Black roots.
3	Boeun, Boeun, Chung Buk	K deficiency. Field near river bank.
4	Oaesuk, Boeun, Chung Buk	Helminthosporium leaf spot present. Severe "Akiochi."
5	Daeya, Oggu, Jeon Buk	A few Helminthosporium leaf spots. Severe "Akiochi." Rotted roots.
6	Hwangyun, Yung Dong, Chung Buk	Many Helminthosporium leaf spots. Field near river bank.
7	Nongso, Kumnung, Gyeong Buk	Severe K deficiency. Rotted roots. Field near river bank. Groundwater emerged in field.
8	Nongso, Kumnung, Gyeong Buk	Symptoms of "Akagare Type I." Field same as Site 7.
9	Ulsan, Ulzoo, Byeong Nam	Leaf tips dead and white.
10	Woongchon, Ulzoo, Gyeong Nam	Many Helminthosporium leaf spots. Field at foot of pine hill.
11	Daejie, Gim Hae, Gyeong Nam	Brown spots in lower leaves. Severe "Akiochi."
12	Juchun, Gim Hae, Gyeong Nam	Symptoms of "Akagare Type I." Slight symptoms of P deficiency. Acid sulfate soil.
13	Samsan, Ulson, Gyeong Nam	Severe symptoms of "Akagare Type I." Rotted roots. Internal drainage poor.
14	Seonghwan, Chunwon, Chung Nam	Leaves pale-green when urea was applied.

Table 3. Analysis of plant samples in Korea.

Site no.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Fe (ppm)	Mn (ppm)	SiO_2 (%)	Zn (ppm)	B (ppm)
1	1 89	0.41	0.37	0.25	0.18	0.22	1800	380	6.0	31	9.0
2	1 96	0.34	0.94	0.12	0.23	0.25	1970	700	5.8	33	4.5
3	1.89	0.12	1.06	0.27	0.11	0.21	2180	700	7.9	25	8 3
4	1.54	0.29	0.75	0.10	0.22	0.35	1290	510	5.6	36	10 0
5	2.17	0.37	1.38	0.18	0.22	0 36	2280	1024	7.7	25	10.5
6	2.03	0.38	1.69	0.23	0.15	0.27	1320	380	5.9	25	10.5
7	3.43	0.56	0.35	0.26	0.20	0.35	1440	640	7.2	30	8.8
8	3.05	0.47	0.63	0.24	0.26	0.31	1440	960	5.7	32	9 3
9	2.31	0 35	1.75	0.18	0.15	0.34	1170	510	7.5	32	4 0
10	2.10	0 16	1.42	0.26	0.16	0.34	1080	450	6 8	27	7.8
11	2.00	0 41	1.68	0.20	0.22	0 28	1700	900	3.6	27	9.0
12	2.66	0 17	1.42	0.27	0 13	0 55	2640	320	8 2	28	10.5
13	3 36	0.37	1.40	0 14	0 33	0.45	1200	640	5 2	26	9 5
14	1 00	0.19	0.74	0 15	0 11	0.14	880	960	6 9	23	2.5

Table 4. Characteristics of soil samples in Korea.

Site no.	Soil pH		CEC*** (meq/100g)	Exchangeable cations (meq/100 g)				Phosphorus absorption coefficient (mg/100g P_2O_5)	Active iron (%)
	Wet soil*	Dry soil**		Ca	Mg	K	Na		
1	—	4.6	6.4	1.8	3.0	0 20	0.56	340	0.39
2	6 40	4.4	7.0	1.8	1.3	0 20	0.17	432	0 37
3	6.35	5.1	3.8	1.7	0.9	0.22	0.15	296	0.25
4	6.15	4.4	6.9	1.4	0.8	0.22	0.10	510	0.19
5	6.60	4.8	8.1	3.4	3.5	0.40	0 83	238	0.45
6	6.10	4.8	5 8	2.2	1.9	0.20	0.12	340	0.15
7	6.60	4.4	4.8	1.8	1 5	0 12	0.10	170	0.43
8	6.10	4.5	6.5	3.4	1.1	0.22	0.25	296	0 50
9	6.40	4.7	5.7	1.8	1.5	0.25	0.17	432	0 18
10	6.20	4.8	7.9	3.4	2.1	0.28	0 15	408	0 25
11	6.50	4.7	7 4	3.6	1.0	0 25	0 66	408	0 43
12	5.20	3 4	16.0	1 8	4.1	1.00	1 55	1224	0 79
13	—	—	—	—	—	—	—	—	—
14	—	4 7	6 3	3 1	1.4	0 45	0 45	432	0.43

* Measured before drying
** In H_2O
*** Cation exchange capacity.

of the plant increases abnormally and plants become susceptible to blast. After some time, the nitrogen supply in the soil is exhausted, the nitrogen content of the plants decreases and they become susceptible to *Helminthosporium*. Such a large fluctuation of plant nitrogen content may be one of the causes of disturbed growth. The fluctuation of potassium content may also be large.

High iron content of the plant may be related to low levels of potassium which decreases the oxidizing power of the roots, thereby permitting more iron to enter the plant. Hydrogen sulfide in the soil solution could have destroyed the oxidizing power of the roots, possibly causing increased uptake of iron and resulting in iron toxicity.

"Akagare Type I"

In fields at Nongso there were patches of plants exhibiting symptoms typical of potassium deficiency as seen in water culture (Site 7). The plants surrounding these patches of potassium deficiency showed typical symptoms of "Akagare Type I." Large brown spots and tiny brown spottings covered the leaves (Site 8).

These symptoms are similar to those of iron toxicity. The plants were low in potassium and high in iron content, indicating an interaction between potassium deficiency and iron toxicity.

Though such serious cases as those described above are rare, they demonstrate the importance of potassium fertilization of rice in this country. The low level of exchangeable potassium and the low cation exchange capacity of the soils indicate that both the amount of potassium to be applied and the method of application are important.

The other case of "Akagare" was observed at Samsan, Ulson (Site 13). The symptoms were brown spots on the leaves which developed to brown discoloration of entire old leaves. The area was very badly

Table 5. Sampling sites in Japan.

Site no.	Site	Note
1	Kitami, Iwate Prefecture	Symptoms of "Akagare Type III" and P deficiency observed at booting stage. Ando soil
2	Kitami, Iwate Prefecture	Symptoms of "Akagare Type III" observed at booting stage. Unhealthy roots. Ando soil.
3	Konosu, Saitama Prefecture	"Akagare Type I" produced on a Chiba sandy soil by pot culture. "Akagare Type II" produced on a Chiba soil by pot culture.
4	Konosu, Saitama Prefecture	"Akagare Type II" produced on a Chiba soil by pot culture.
5	Konosu, Saitama Prefecture	"Akagare Type III" produced on a Mikatagahara soil by pot culture.
6	Himezi, Hyogo Prefecture	Helminthosporium leaf spot present. Severe "Akiochi." Silty river-alluvial soil of liparitic origin.
7	Koyama, Emi Town, Chiba Prefecture	White discoloration of midrib in upper leaves. White discoloration of midrib and brown spots or streaks in margins of lower leaves. Brown discoloration of entire leaves. Tillering active, but plant height short Leaf sheaths long, but leaf blades short Located on upper portion of hillside. Soil with broken pieces of serpentine.
8	Jononai, Chosei Town, Chiba Prefecture	Symptoms similar to those at Koyama (Site 7)· Area newly reclaimed from river bed. Salt injury in first 2 to 3 years of reclamation, "Akagare," in subsequent years
9	Okura, Sahara City, Chiba Prefecture	Symptoms same as in Site 7, but more severe· Sandy soil with broken shells.

drained and the roots of the plants were completely blackish, indicating a high level of hydrogen sulfide in the soil. The plant samples were characterized by high nitrogen content, a rather high level of iron, and a low calcium content.

On an acid sulfate soil at Juchun, Gim Hae (Site 12), the plants were showing typical "Akagare" symptoms. Iron content of the plant was very high and phosphorus content low. Iron toxicity was the major cause of the retarded growth, but phosphorus would have been the growth-limiting factor if soil pH were adjusted.

An experiment being conducted at the site indicated that application of calcium carbonate or calcium silicate is very effective. This can apparently be attributed to adjustment of pH. It was also clearly demonstrated that drainage greatly improves plant growth. This situation is somewhat different from that of other acid sulfate soils where drying the soil lowers the pH and makes iron toxicity more serious. However, in this case it seems that oxidizing the soil decreases iron solubility and corrects iron toxicity. Removal of sulfate (sulfuric acid) by internal drainage may be another reason for the remedial effect of drainage.

Other possible nutritional disturbances

Generally speaking, the silica content of the sample plants was low. Many experiments with silica-containing materials have demonstrated that these materials, especially wollastonite (calcium silicate), are effective in improving growth, suggesting that low silica may be one of the factors causing low grain yield.

Sometimes, the calcium or magnesium content of the plants was rather low. The soils had a low calcium and magnesium supply, and the irrigation water was also suspected to be low in these bases. Although deficiency symptoms were not apparent, there may have been a positive response to these elements in the field. The positive effect of slag or wollastonite may be attributed, at least partly, to their calcium contents.

In one of the field experiments at Seonghwan, Chunwon (near Pung Taek), ammonium sulfate plots were apparently superior to urea plots. The area is near the bank of a river leading from a disused gold mine. The soil is sandy, and "Akagare" was reported to be serious at an early stage of the reclamation of the land. The plants on urea plots were weakly tillered and yellowish. These symptoms are similar to those of nitrogen or sulfur deficiency. The problem may be caused by sulfur deficiency of rice in the field, but further study is necessary.

Boron deficiency has been reported in South Korea in upland crops such as barley, rape, cabbage, etc. No boron deficiency symptoms in rice were observed, although the boron content of some sample plants was low. Drying of leaf tips and a white color were

Table 6. Analysis of plant samples in Japan.

Site no.	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Fe (ppm)	Al (ppm)	SiO_2 (%)	Zn (ppm)	N (ppm)
1	0.08	2.84	0.34	0.14	2400	196	289	8.43	—	—
2	0.15	3.08	0.30	0.14	600	193	185	3.56	—	—
3	0.32	1.52	0.70	0.27	88	448	129	4.02	—	—
4	0.38	3.19	0.73	0.38	150	502	222	5.02	—	—
5	0.08	2.28	0.45	0.08	556	228	295	3.41	—	—
6	0.25	3.55	0.42	0.20	656	184	181	7.76	—	—
7	—	2.30	—	—	225	370	—	10.9	7	10
8	—	1.70	—	—	175	346	—	7.4	28	2
9	—	1.90	—	—	150	192	—	11.5	9	*

*Trace.

Table 7. Characteristics of soil samples in Japan.

Site no.	pH	CEC* (meq/100 g)	Exchangeable cation (meq/100 g)				OM** (%)	Phosphorus absorption coefficient (mg/100g P_2O_5)	Active Fe (%)	Easily reducible Mn (ppm)
			Ca	Mg	K	Na				
1	5.00	40.1	4.5	2.2	0 48	0 26	19.0	2221	0 66	350
6	6.02	9.9	6.0	2.5	0.74	0.26	2.4	114	0.19	75
9	8.10	6.3	—	—	—	—	1.0	—	—	—

* Cation exchange capacity.
** Organic matter.

frequently observed. This appears to be nematode damage, but it is possible that boron deficiency caused the observed symptoms.

JAPAN

Japan* is a chain of islands, stretching from north (about 46°N) to south (about 26°N). Hokkaido, Honshu, Shikoku, and Kyushu are the four main islands. It is a volcanic country, and soils of volcanic ash origin are widely distributed. Soils derived from granite, liparite, and sandstones are found in the southern part of Honshu and Shikoku islands where "Akiochi" was once a serious problem. This has been controlled by various methods and typical cases are now rare. "Akagare," of which there are several types, still occurs in some places.

Samples were taken at nine sites as shown in Figure 2 and Table 5. Analytical data on plants and soils are listed in Table 6 and Table 7.

"Akiochi"

An example of "Akiochi" was observed on an alluvial soil along the river Ichikawa near Himeji City (Site 6). The plants were at booting stage and the leaves were

*Trips were made to Japan in August 1965 to observe the general status of nutritional disorders, and frequently in 1965-66 to make close inspections of "Akagare" in Chiba prefecture.

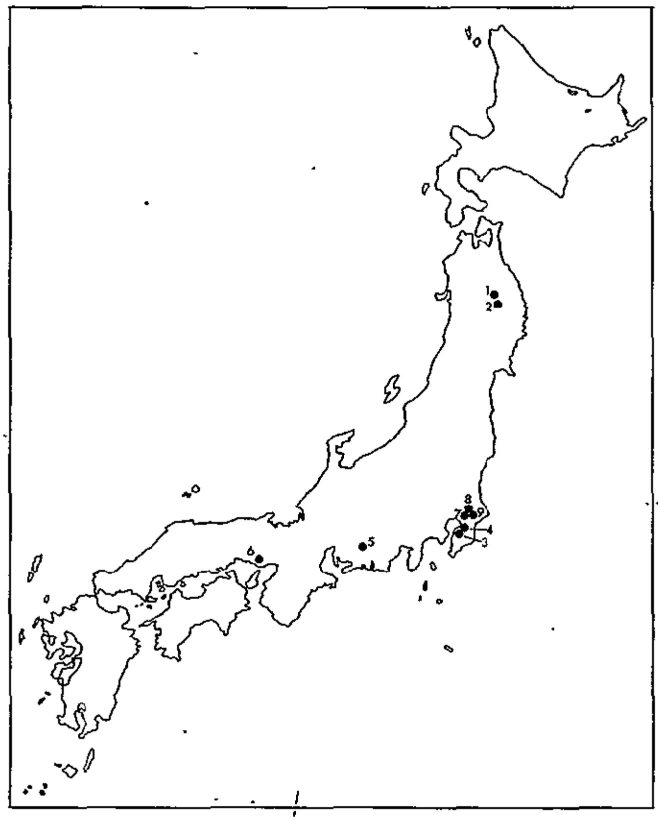

Fig. 2. Survey sites in Japan.

extremely soft. The plants were dirty green, their leaves had started to die, and there were many *Helminthosporium* leaf spots. Roots were sparse and light reddish mixed with black. The soil is derived from liparite or granite and there is a gravel layer below the surface soil. It has a low cation exchange capacity and active iron content. Winter crops on this soil, such as barley, suffer from magnesium or manganese deficiency. The sample plant did not show any peculiarity in its nutrient contents. However, the cause is considered to be toxicity of hydrogen sulfide associated with low levels of silica and various bases.

"Akagare"

At the Central Agricultural Experiment Station, Konosu, Dr. I. Baba and his group demonstrated three types of "Akagare" produced on potted rice plants. The diagnosis of the symptoms seen in the fields was based on the symptoms observed in these pot demonstrations.

"Akagare Type I"

The symptoms demonstrated at Central Agricultural Experiment Station (CAES) were reproduced on a Chiba sandy soil high in organic substances (Site 3). The symptoms, which developed about 1 month after transplanting were brown spots on interveins which generally began at the leaf tip and spread to the leaf base. The sample had low potassium content.

This disorder can be remedied by potassium application. However, the symptoms are not necessarily identical with those of potassium deficiency produced in water culture; potassium deficiency produced in water culture does not usually include tiny brown spots, although these are developed with iron toxicity.

Simple pot experiments in a greenhouse, using soils on which "Akagare" develops, indicated an interaction between potassium deficiency and iron toxicity. Rice may suffer from iron toxicity which can be corrected by application of potassium. Hence, the disorder can be regarded as potassium deficiency associated with iron toxicity. The critical toxicity level of iron may increase with the increase of potassium.

"Akagare Type II"

The symptoms demonstrated at CAES were also developed on a Chiba soil high in organic substances (Site 4) and to which starch was added. The symptoms are chlorosis of the midrib of the young growing leaves, brown discoloration which develops later on the leaves on both sides of the chlorotic midrib, and a red-brown discoloration which finally covers the whole leaf. The disorder generally develops on ill-drained soil high in organic substances and is not controlled by potassium application, though it is improved to some extent.

It is reported that the decomposition products of organic substances under reduced conditions, such as high iron level, organic acid, hydrogen sulfide, etc., are the causative factors of the disorder. However, this is not supported by conclusive experimental evidence.

During the survey, "Akagare" was observed at several places in Chiba Prefecture as listed in Table 5 (Sites 7, 8, 9). The symptoms were identical with those of "Akagare Type II" and very similar to those of zinc deficiency symptoms produced in water culture. Analysis of sample plants (Table 6) indicated low zinc content of samples No. 7 and No. 9. Thus, it was strongly suspected that the cause of this disorder was zinc deficiency.

At Koyama, Emi Town, the soil is of serpentine origin with high pH and high magnesium and nickel content. Interaction between zinc and nickel may be one of the causes of the abnormality. At Okura, Sahara City, the soil is sandy, contains a large amount of broken shells, and has a high pH (8.0 to 8.5). The area is low lying on the bank of the Tone River, and rice had been harvested by boat. In that spring, sand on the bed of the Tone River was pumped up with the water and spread over the area to a depth of 1 meter to elevate the fields. In lower patches salt injury was serious because of the brackish Tone River water. Rice in elevated areas was suffering from "Akagare". High soil pH seems related to this disorder. A greenhouse experiment with Okura soil demonstrated that application of zinc improves growth and remedies the "Akagare" symptoms.

Based on these observations, it can be concluded that at least some examples of "Akagare Type II" are caused by zinc deficiency.

"Akagare Type III"

The symptoms demonstrated at CAES were also seen on a Mikatagahara soil which was diluvial, of volcanic origin, reddish in color, low in pH, high in active aluminum, and high in phosphorus absorption coefficient (Site 5). In severe cases, plants were almost dead and had symptoms of phosphorus deficiency. In milder cases, the plants had a limited number of tillers and erect leaves with brown spots. The spots started to develop from the tips of old leaves and spread along the interveins. There were also brown spots on the leaf sheath, and the tissues at the base of the culm became brown. The sample plant was low in phosphorus.

In Iwate Prefecture, rice fields are now being expanded to diluvial high land where volcanic ash has been deposited. Since 1960, a disorder has become a problem on the newly opened rice fields. The symptoms observed (Sites 1, 2) were similar to those observed on the demonstration plants at CAES. The sample plants were characterized by high manganese and low phosphorus contents.

Table 8. Analysis of plant samples in Taiwan.

Site no.	Location	N (%)	P (%)	K (%)	Na (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Al (ppm)	SiO_2 (%)
1	Tungsham, Ilan	1.75	0.19	1.84	0.93	0 36	0.23	178	1825	299	7.7
2	Pingtung	1 27	0 12	2 44	0.91	0.37	0.26	144	338	184	10 1

Table 9. Characteristics of soil samples in Taiwan.

Site no	pH (H_2O)	CEC* (meq/100 g)	Exchangeable cations (meq/100 g)				OM** (%)	Phosphorus absorption coefficient (mg/100g P_2O_5)	Active Fe (%)	Easily reducible Mn (ppm)
			Ca	Mg	K	Na				
1	6 35	7 9	12 5	2 5	0 20	0 44	4.0	573	0.51	380
2	7 10	11.8	25 0	4 2	0 51	0.17	5.7	573	0.19	130

* Cation exchange capacity
** Organic matter

The disorder appears in the first year after the rice field is opened. Rice suffers most in those fields that were converted from pine forest; those formed from wild grassland are the next most affected, and those from upland fields the least. The disorder is more common on ill-drained than on well-drained fields. On the latter, it appears in the first year but not in the second, whereas on the ill-drained fields the disease continues to appear for several years after reclamation.

There are, apparently, varietal differences in susceptibility to this disorder. Chokai, Hatsunishiki, etc., are resistant and Towada, Fujisaka 5, Fujiminori, etc., are susceptible. On resistant varieties, brown spots may not appear, although the plants are not apparently completely healthy.

The soil was usually poor in available phosphorus and phosphorus deficiency symptoms were seen in some fields with symptoms of "Akagare Type III" in others. Application of phosphorus improves growth but does not necessarily reduce the incidence of brown spots. The cause of the disorder is now suspected to be iodine toxicity.

TAIWAN (CHINA)

Taiwan* lies in the subtropical to tropical regions. As described earlier, "suffocation disease" has been a serious problem. Special efforts were therefore made to examine conditions referred to as "suffocation disease" during visits to Ilan, Taichung, Chiayi, Kaohsiung, and Pingtung.

Samples were taken at Ilan and Pingtung (Fig. 3), because plants appeared to be suffering from nutritional disorders. Analytical data on these samples are given in Tables 8 and 9. "Suffocation disease" was serious at Luying in Chiayi district but since the cause of this disorder was apparently a virus, no samples were taken.

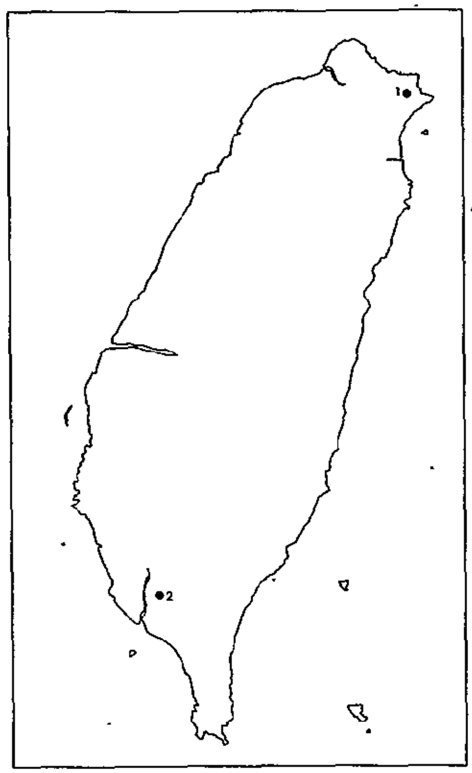

Fig. 3. Survey sites in Taiwan.

"Suffocation disease" (Transitory yellowing)

"Suffocation disease" is a loose term. It does not refer to a disorder caused by a definite parasite or have precise symptoms.

*Visits were made in October and November 1962, and in October 1964.

In the Taichung and Chiayi area the disease used to be serious. In this area three crops are grown each year, two lowland crops and an upland one between them. Because of limited time, rice has to be transplanted immediately after flooding and a large amount of compost is generally applied. These conditions suggest that rapid decomposition of organic substances under flooded conditions may be the cause of the disorder referred to as "suffocation disease."

It was long considered that the disorder was related to soil reduction under flooded conditions. However, a recent experiment in Chiayi district shows that the disorder is apparently caused by insect damage, or by viruses transmitted by insects. Many plants were apparently affected by viruses, and many dead plants appeared to have been attacked by leafhoppers. The experiment demonstrated that the disorder can be eliminated by applying Sevin in the seedbed and in the main field. Screening the seedbed also gave excellent results. Later, the disorder was successfully transmitted by leafhoppers. There is no doubt that the disorder is caused by a virus known as "transitory yellowing."

Signs of the disorder are sometimes so uniform in a plot that it is difficult to believe that it is caused by a virus or other pathogen. However, a serious virus attack can destroy a plot uniformly.

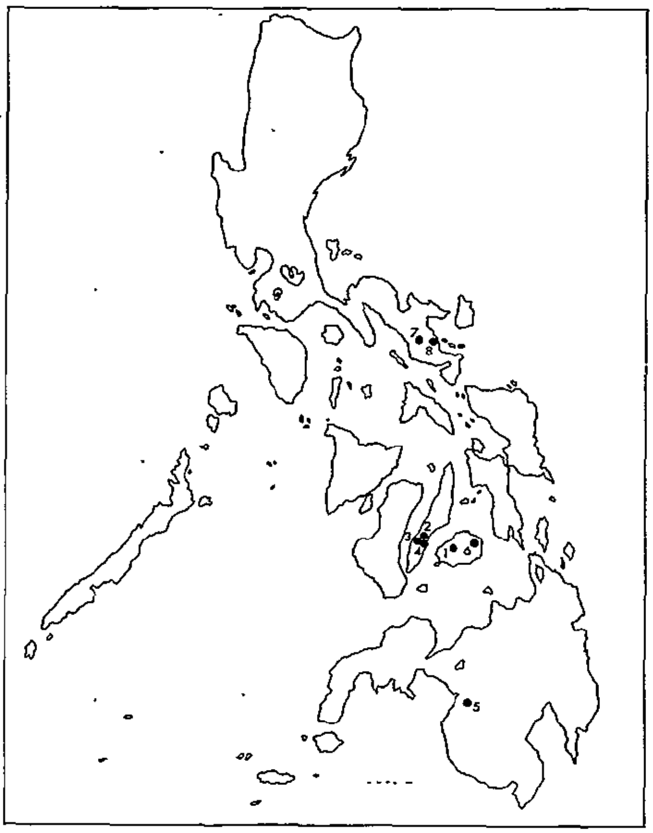

Fig. 4. Survey sites in the Philippines.

"Suffocation disease" (Brown-spot type)

In Ilan district, rice was suffering from an abnormality characterized by a reddish-brown discoloration of the leaves, stunted growth, and root rot. This disorder was also referred to as "suffocation disease." It had some similarities to potassium deficiency. In Pingtung, rice suffers from a similar disorder at early stages of growth.

Analysis of the plants did not give any definite information on the cause of the disorder.

An experiment in Ilan district, in which different levels of potassium were applied, demonstrated an apparent positive effect of potassium application. A positive effect of silica and manganese oxide application was also claimed. It was reported that manganese dioxide and calcium nitrate retard the fall in Eh of this soil after flooding, thereby effecting some improvement (*89*).

The soils in Ilan and Pingtung have a pH of 6 to 7 and the sum of the exchangeable cations exceeds the cation exchange capacity. The pH of the subsoils is between 7.4 and 7.9. In both districts, there are large deposits of limestone, and it is possible that the soil contains considerable amounts of calcium carbonate. Under flooded conditions, increased concentration of bicarbonate results in increased solubility of calcium, resulting in a high ratio of calcium to potassium in the soil solution. Rice may suffer from potassium deficiency as a consequence. However, the actual cause of this disorder is not yet known.

Boron toxicity

Ponnamperuma *et al* (*91*) reported boron toxicity in a pot experiment with a soil from the Silo region on the coast of Taiwan. The observed symptoms were roughly identical with those of boron toxicity on rice in solution culture. The boron content of the plants was 80 ppm. The soil was a slightly saline, alkaline (pH 8.1), silty loam; the soil solution contained 9.1 ppm B.

PHILIPPINES

The Philippines* consists of a chain of islands, stretching almost a thousand miles from north (about 22°N) to south (about 4°N). The two biggest islands, Luzon and Mindanao, are located in the north and south, respectively. Other large islands between these are Mindoro, Samar, Panay, Negros, Cebu, Bohol, Palawan, Masbate, and Leyte. There are many volcanoes in the Philippines, mostly extinct or dormant, although at least four are still active. Mount Taal, near Manila, and Mount Mayon, in Southeast Luzon, erupt quite frequently.

*Visits were made frequently between 1965 and 1969.

Table 10. Sampling sites in the Philippines.

Site no.	Site	Note
1	Riverside, Bohol	K deficiency. Many Helminthosporium leaf spots. Area low-lying and poorly drained. Soil from coralline limestone.
2	Minglanilla, Cebu	Plants stunted. Yellowing 2 weeks after transplanting; rusty brown spots in lower leaves. Some recovery in plant growth at later growth stages.
3	San Isidro, Talisay, Cebu	P deficiency.
4	Carcar, Cebu	Symptoms same as in site 1.
5	Makilala, Cotabato	Symptoms similar to P deficiency. Field at lower portion of a rubber plantation
6	Bueno Suerto, Bohol	P deficiency. Helminthosporium leaf spot present.
7	Libon, Bicol	Brown spots and browning along midrib of lower leaves 3 to 4 weeks after transplanting. High percentage of unfilled grains.
8	Camarines Sur	Seedlings dead few days after transplanting. Even weeds not growing in field or on levee. Acid sulfate soil.

Table 11. Analysis of plant samples in the Philippines.

Site no.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Fe (ppm)	Mn (ppm)	Al (ppm)	SiO_2 (%)
1	1.85	0 20	0.49	1.30	2.68	4.36	165	78	245	5 86
2	2.64	0 20	1.32	1.25	0.56	3 06	604	188	360	12.74
3	1.85	0 12	1.37	0.78	0.40	2.33	144	72	88	8.66
5	1.82	0 18	2.50	0.35	0 57	1 24	947	469	170	10 82
6	2.09	0.05	1 95	0.46	0 28	1.15	588	750	—	11 10

Table 12. Characteristics of soil samples in the Philippines.

Site no	pH	CEC* (meq/100 g)	Exchangeable cations (meq/100 g)				OM** (%)	Phosphorus absorption coefficient (mg/100g P_2O_5)	Active Fe (%)	Easily reducible Mn (ppm)
			Ca	Mg	K	Na				
1	7.4	40.9	47.0	4.3	0.18	0.30	14.8	1901	0.09	7
2	7.4	28.1	55.0	15.8	0.20	1.52	4.2	1442	0 46	154
3	7.4	40.9	61.10	14 2	0 31	0.78	4.7	1992	0.31	82
5	5.3	15 1	5.5	4.0	0 82	0.57	3.7	1122	0 90	263
6	5.7	32 4	18 0	5 8	0 59	1.96	1.5	1397	1 29	1350
7	7.2	63 2	54 0	8.8	0.43	1.10	5.3	2760	0.75	—
8	3.8	12.5	6.14	0.76	0.12	0.43	3.5	—	0.96	—

* Cation exchange capacity
** Organic matter

Calcareous soils developed from coralline limestones are distributed throughout the Philippines, not only near the coast but also in highly elevated areas. Soils of volcanic ash origin are found in many places. In hilly areas the soils are reddish-brown to brown and usually with low pH.

During survey trips covering part of Luzon, Mindanao, Cebu, and Bohol, abnormal rice fields were frequently observed on soils derived from coralline limestones. Paddy fields were examined where the standing water contained a very high concentration of iron compounds, but in which no iron toxicity symptoms were observed. In such cases, phosphorus deficiency was common. A disorder of rice on acid sulfate soils was also observed but the affected area is probably not large. Zinc deficiency was identified on a calcareous soil in Cebu.

Sampling sites are shown in Figure 4 and Table 10; analytical data are given in Tables 11 and 12.

Table 13. The results of pot experiments on Libon soil.

Treatment	Panicle weight (g)	Straw analysis (%)				Soil leachate analysis*	
		P	K	Fe	Mn	Fe (ppm)	Mn (ppm)
NPK	153	0.12	1.63	0.12	0 02	10	7
NK	143	0.10	1.47	0.03	0.02	—	—
NP	71	0.25	0 91	0.03	0.03	10	5
NPK-drained**	110	0 12	1.93	0.01	0.02	2	3

* Three weeks after transplanting.
** Water was drained in the morning and returned in the afternoon, repeated twice a week.

Potassium deficiency on calcareous soils

In rice fields where soils are derived from coralline limestones in Bohol and Cebu (Sites 1, 4), plants showed potassium deficiency symptoms with heavy infestation of *Helminthosporium*. The plants were low in potassium and phosphorus, but high in calcium.

The soils had an aerobic pH of 7.4 but under flooded conditions the pH was about 6.7 to 6.8. A low potassium and high calcium level may be the cause of the disorder. High pH combined with high calcium makes availability of phosphorus low.

Pot and field experiments at Site 1 indicated that application of potassium and phosphorus improves growth and grain yield significantly *(37)*.

In the Libon area, Bicol region, there is a disorder known as "Natutunaw" (literally, "going to die") of which the visible symptoms are stunting and the appearance of brown spots and browning along the midrib. The soil is alkaline and high in calcium and organic matter, and has a high phosphorus absorption coefficient. The results of a pot experiment indicated that potassium deficiency is a problem on this soil (Table 13) although the exchangeable potassium content is not low. Brown discoloration appeared in all the pots except one, from which the water was drained. Application of potassium improved plant growth but did not correct the browning symptoms. It was obvious from plant and soil leachate analysis that the brown discoloration was not caused by iron toxicity.

In calcareous soils that also have low levels of potassium, deficiency of potassium is one of the causes of the disorder. In addition, increase in calcium or bicarbonate concentrations in the soil solution, or formation of other substances under submerged conditions, may be responsible for the disorder.

Zinc deficiency on a calcareous soil

The visible symptoms of a disorder found on a calcareous soil in Cebu (Site 2) were very similar to those of zinc deficiency. Analysis of the affected plant showed very low zinc content. The disorder is locally called "Taya-Taya," and occurs in the same place every year. It is characterized by yellowing about 2 weeks after transplanting, followed by stunted growth and rusty brown spots on lower leaves. Growth usually recovers to some extent at later stages. The soil is calcareous with a high pH.

To confirm zinc deficiency on Minglanilla, Cebu soil, rice plants were grown in the greenhouse with and without added zinc. About 3 weeks after transplanting, the plant without added zinc developed chlorosis along the midrib, brown spots and blotches, and growth was very stunted. As shown in Table 14, addition of zinc resulted in a remarkable increase in dry weight, and this was associated with increased zinc content. Visible symptoms, plant analysis, and the greenhouse experiment all indicated that this is indeed an example of zinc deficiency in the field.

Phosphorus deficiency on soils with low pH and high in active iron

There are soils high in active iron and easily reducible manganese but with low pH (Site 6). On these soils, rice plants frequently show phosphorus deficiency symptoms. The plants are low in phosphorus and high in iron and manganese.

This type of abnormality is common in the Philippines on rice fields in hilly areas with basic rocks. The rocks are in the early stages of lateritic weathering, and the soils have a low pH and much active iron and aluminum. Such soils have a high phosphorus absorption coefficient.

Disorder on acid sulfate soil

In Camarines Sur (Site 8), farmers reported that in the 1967 wet season seedlings died completely a few days after transplanting. This had never happened previously in 20 to 30 years of rice cultivation.

Table 14. Effects of zinc application on dry weight and zinc content of the rice plant on Minglanilla, Cebu soil.

Zn added (ppm)	Dry weight (g)	Zn content (ppm)
0	0.53	19
40	1.73	33

Table 15. The results of pot experiments on Camarines Sur soil.

Treatment	Dry weight (g)	Straw analysis			Soil leachate*		
		P (%)	K (%)	Fe (%)	pH	EC** (Micromhos/cm)	Fe (ppm)
No lime	—	—	—	—	7.0	6900	2700
0.25% $CaCO_3$	0.08	0.13	1.23	1.53	6.9	6000	1650
0.50% $CaCO_3$	1.60	0.15	1.31	0.05	6.9	4800	1100
0.75% $CaCO_3$	4.46	0.14	1.19	0.03	6.9	3000	830

* Three weeks after transplanting.
** Electrical conductance

The problem site was located several hundred meters from the coast, and at the time of our visit, there were dead seedlings in the field. There was almost no weed growth in the field or on the levees. The pH of the wet soil was 6.6, and the fields were in low-lying areas which do not usually dry out completely in the dry season. However, in 1967, the fields dried out for 3 to 4 months before the regular rice crop season.

Analysis of the soil indicated that it had low pH, contained 0.31 percent sulfate, and could be regarded as a moderate acid sulfate soil.

Results of a pot experiment are shown in Table 15. Without lime, the plants died 4 days after transplanting. Lime application improved plant growth remarkably.

Soil leachate analysis indicated that higher concentrations of ferrous iron were associated with higher values of electric conductance. It must be pointed out that an electric conductance of about 7,000 micromhos/cm can cause serious damage to rice seedling establishment (*38*). Typical iron toxicity symptoms were observed on rice leaves on plots with 0.25 percent and 0.5 percent calcium carbonate.

In 1968, we visited the same field and found a healthy crop without any ameliorative measure having been taken. The fields had not been dry since the 1967 wet season.

This observation agrees with what is known about chemical changes in acid sulfate soils and emphasizes the importance of continuous flooding of such soils to prevent high concentrations of ferrous iron and high electric conductance.

THAILAND

Thailand* is bordered on the northeast by Laos, on the southeast by Cambodia, on the south by the Gulf of Thailand and Malaya, and on the northwest and west by Burma. It is a tropical country, located between about 5°N and 20°N.

The country is almost completely bordered on three sides by mountains which enclose the extensive plain of the Menam Chao Phya. The present survey covered part of the central plain and Korat Plateau region. During the survey, all observed disorders of rice were on acid soils.

After nitrogen, phosphorus seems to be the most important limiting nutrient in Thailand. Sample sites are shown in Figure 5 and plant symptoms and chemical analysis of plant and soil samples are recorded in Tables 16, 17, and 18.

*Visited in September 1967.

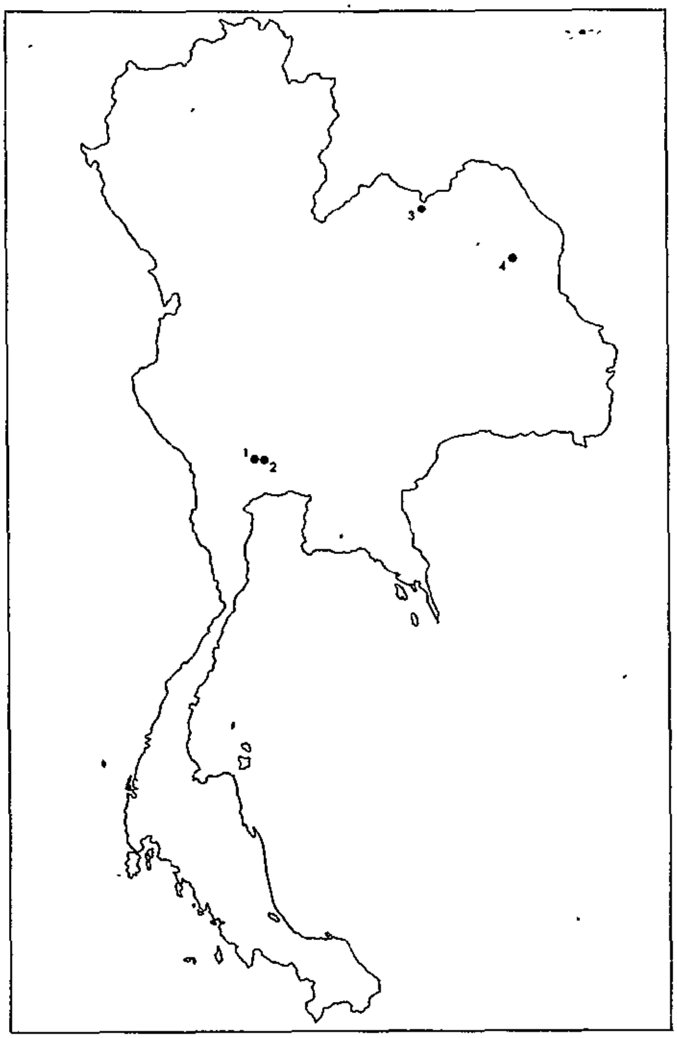

Fig. 5. Survey sites in Thailand.

Table 16. Sampling sites in Thailand.

Site no.	Site	Note
1a	Pathumthani	Yellowish-white discoloration of lower leaves
1b	Pathumthani	Phosphorus deficiency symptoms
2	Pathumthani	The same as site 1a.
3a	Udornthani	Typical iron toxicity symptoms.
3b	Udornthani	Yellowish discoloration
4	Sakol Nakorn	Iron toxicity symptoms

Phosphorus deficiency and iron toxicity

In areas north of Bangkhen on the Central Plain (Sites 1, 2) we observed rice plants with unusual symptoms—, yellowish-white discoloration of lower leaves. We were told that aluminum toxicity is the suspected cause. The soil pH was low, about 5.5, at the time of our visit and 4.6 on air-dried samples. Chemical analysis indicated that the plants were deficient in nitrogen or phosphorus, or both. There seemed to be no indication of aluminum toxicity.

On the Korat plateau, there are about 2 million ha of problem soils: Roi Et sandy loam, 800,000 ha; Ubon sandy loam, 600,000 ha; and 600,000 ha of other soil types. Soils in this area are characterized by low pH, low organic matter content, and extremely low cation exchange capacity.

Rice in this area was generally showing acute phosphorus deficiency and, in addition, typical symptoms of iron toxicity were observed at two places. In Udornthani (Site 3), an entire field was affected by severe iron toxicity but in an adjoining field the plants showed only a pale orange-yellowish discoloration without tiny brown spots. An affected plant was high in iron and low in potassium content.

In Sakol Nakorn (Site 4), typical symptoms of iron toxicity were observed in a field of the Rice Experiment Station. An affected plant was high in iron content but its potassium content was not necessarily too low. Considering the extremely low content of exchangeable potassium in the soils, however, it is very likely that potassium deficiency will become a problem when rice growth is improved by the introduction of better varieties, application of nitrogen and phosphorus, and improvement of other cultural practices.

MALAYSIA

The main part of Malaysia* is a peninsula located just above the equator (1°N to 6°N). In hilly areas, found in the central part of the peninsula, rubber is planted very extensively and oil palms to a lesser extent. Rice is grown mainly on soils developed from marine and riverine sediments along the coast. The present survey covered only the west coast of the pensinsula from Alor Star to Malacca.

In the Krian area, typical "Penyakit Merah" (yellow type) was examined. Observations made at the

*Visits were made in 1964 and 1968 to observe "Penyakit Merah," a well-known disorder in Malaysia, and the general status of nutritional disorders of rice

Table 17. Analysis of plant samples in Thailand.

Site no.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	SiO_2 (%)	Fe (ppm)	Mn (ppm)	Al (ppm)	Zn (ppm)
1a	0.98	0 06	1.80	0 14	0.26	1.13	9.9	791	522	476	40
1b	0.74	0 06	1.90	0 19	0.13	0.15	11.9	683	975	425	58
2	0 66	0 13	1.30	0 09	0.14	1.38	9.9	354	551	322	59
3a	1.19	0.22	0.90	0.15	0 08	0 55	7 6	861	750	366	33
3b	2 38	0.25	1.25	0.10	0.17	0.28	7.2	648	522	290	35
4	1 27	0 31	1.53	0.15	0.10	0.65	5.9	837	471	553	14

Table 18. Characteristics of soil samples in Thailand.

Site no	pH (H_2O)	CEC* (meq/100 g)	Exchangeable cations (meq/100 g)				OM** (%)	Available*** phosphorus (ppm)	Phosphorus absorption coefficient (mg/100g P_2O_5)	Active Fe (%)
			Ca	Mg	K	Na				
1	4 6	27.4	11 27	5.48	0 77	0.60	2.76	0 4	1932	0 67
3	5 8	3 8	0 68	0 10	0.06	0 22	0 53	0.4	782	0.09
4	5 2	2 8	1 17	0 26	0 06	0.43	0 93	3 1	782	0 03

* Cation exchange capacity
** Organic matter
*** Olsen's method

Table 19. Sampling sites in Malaysia.

Site no.	Site	Note
1	Krian	"Penyakit Merah" (yellow type). Ill-drained marine alluvial. Soil had decomposed peaty material.
2	Alor Gujah, Malacca	"Penyakit Merah" (brown spot type). Symptoms same as Fe toxicity. Lateritic hilly area.
3	Pulan Gadon, Malacca	P deficiency and Fe toxicity symptoms. Acid sulfate soil.
4	Malacca-northern part of Malacca	Severe Fe toxicity symptoms, but fairly good crop (ripening stage). Peaty soil.
5	Alor Star, Idris	Severe Fe toxicity symptoms at panicle initiation. Acid sulfate soil.
6	Alor Star, Guwara	Severe Fe toxicity symptoms at tillering stage. Acid sulfate soil.
7	Bukit Merah	Severe Fe toxicity symptoms at maximum tiller number stage. Acid lateritic soil.

site strongly suggested that the disorder was caused by virus, rather than being physiological. In Malacca, however, a typical case of iron toxicity was observed on a lateritic soil and on both acid sulfate soils and peaty soils in a coastal area. This type of disorder is also sometimes locally called "Penyakit Merah" (brown-spot type). In the northwest coast region, typical iron toxicity symptoms were frequently observed on soils suspected to be acid sulfate soils. Iron toxicity seems to occur widely on the west coast of Malaysia and is mainly associated with acid sulfate soils although it is sometimes associated with lateritic soils, too. Plant and soil samples were taken at the places shown in Figure 6 and Table 19. Analytical data of plant and soil samples are listed in Tables 20 and 21.

Iron toxicity

The symptoms observed at Alor Gujah (Site 2) were examples of what is known as the brown-spot type of "Penyakit Merah" and were typical of bronzing symptoms. The plants were fairly high in iron but low in manganese. Potassium content was normal. The area had rubber plantations on the lateritic hills and rice in the valleys.

Rice field soils are apparently derived from lateritic materials eroded from the high area. The soils have low pH and cation exchange capacity. Under flooded conditions, they are yellowish-gray with pH 6.3. An iron film was observed on the surface of standing water in the field.

The symptoms at Pulan Gadon (Site 3) were not typical of bronzing at the time of our visit, but typical bronzing was observed at other places where plants were at a more advanced stage. The sample plants contained adequate potassium, but were high in iron and low in manganese. The rice fields in this area were reclaimed from acid sulfate soils several years ago.

Acid sulfate soils are being reclaimed in this area. Plants in the newly reclaimed fields had typical bronzing symptoms. The soil consists of marine alluvium and peat derived from a mangrove swamp. After the drainage canal was constructed, the content of organic substances fell. The soil has a pH of 3.5 when it is dry, caused by sulfuric acid derived from sulfide by oxidation. White precipitates of aluminum and ferric sulfates were present on the surface of the dry soil.

In Malacca, another example of iron toxicity was observed on a peaty soil (Site 4). The crop was ripening and reasonably well grown, but the leaves showed rather severe symptoms of iron toxicity.

In Alor Star, northwest coast, typical iron toxicity was observed at two places (Sites 5, 6). The soils were regarded as acid sulfate soils. It was interesting to learn that the paddy fields in this area have been growing rice for many years, and that the farmers were experiencing the malady for the first time after a long drought. It has, however, been customary to transplant two or three times before a satisfactory crop can be established.

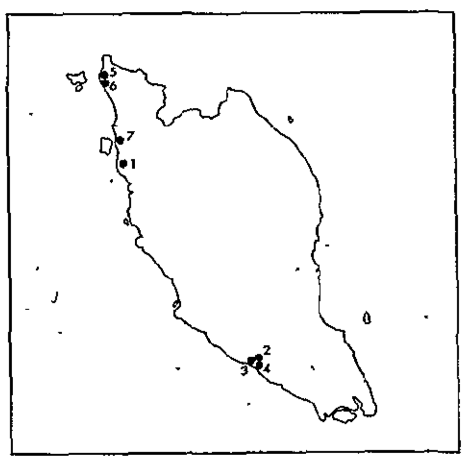

Fig. 6. Survey sites in Malaysia.

Table 20. Analysis of plant samples in Malaysia.

Site no.	N (%)	P (%)	K (%)	Na (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Al (ppm)	SiO_2 (%)
1	1.86	0.14	4.57	0.88	0.29	0.38	214	213	459	8.53
2	2.83	0.19	2.99	0.62	0.31	0.28	606	88	204	5.49
3	2.32	0.23	3.36	2.34	0.29	0.28	648	50	408	6 82
5	2.49	0.22	1.31	0.64	0 18	0.09	200	100	—	—
6	2.78	0.14	1.42	0.09	0.16	0.08	3300	100	—	—

Table 21. Characteristics of soil samples in Malaysia.

Site no.	pH (H_2O)	CEC* (meq/100 g)	Exchangeable cation (meq/100 g)				OM** (%)	Phosphorus absorption coefficient (mg/100g P_2O_5)	Available phosphorus (ppm)	Active Fe (%)	Easily reducible Mn (ppm)
			Ca	Mg	K	Na					
1	6.2	30.9	8.0	35.0	1.05	2.56	4.1	1053	—	0.13	68
2	4.8	8 1	2.0	1 2	0.31	0 30	5.3	847	—	0.57	·4
3***	4 1	13 6	1.5	1.2	0.33	0.20	4 1	802	—	0 74	23
3****	3 5	41.3	0.8	2 8	0.23	2.83	19 0	1626	—	1.04	0.5
4	4 5	37.8	2 04	4 53	0.14	0.73	26.5	1748	14	0.80	—
5	4.2	22.0	2.40	2.50	0.38	1.61	5.7	920	16	0.44	—
6	3.8	17 8	1.30	1.35	0.29	0.50	5.2	1196	4	0.59	—
7	4.2	11.5	2.57	2.68	0.13	0.91	3.4	322	12	0.20	—

* Cation exchange capacity
** Organic matter.
*** Paddy field
**** Virgin soil.

The first or second transplanting does not usually establish a good stand.

About 300 meters from Bukit Merah Rice Station (Site 7), severe iron toxicity was observed. The soil was lateritic with a low pH. In this field, weeds had been very vigorous before the crop was planted and were incorporated into the soil before transplanting.

These observations indicate that iron toxicity is widely scattered and mostly associated with acid sulfate and lateritic soils.

"Penyakit Merah" (Yellow Type)

The term "Penyakit Merah" has apparently been loosely applied to any condition that changes the rice leaves to yellow or orange. Kanapathy* mentioned that the disorder exhibited at Krian was the authentic yellow type of "Penyakit Merah" (Site 1).

In the Krian district, about 27,000 ha of irrigated rice are grown on marine alluvial soils. Between the river and marine alluvium, there are well-decomposed peaty soils developed from mangrove swamp. In this low-lying coastal area water stays in the field throughout the year. Only one crop of rice is grown annually, starting in September. The method of land preparation is unusual. Grass is cut with a "tajak" (big sickle) and allowed to decompose in the field. After a month or so, rice seedlings are transplanted without plowing. The soils are extremely clayey. This method leads to a highly reduced soil condition.

Since the disease, "Penyakit Merah" (Yellow Type), is restricted to reduced soils developed on marine alluvium, the disorder was thought to be a physiological one associated with soil reduction.

The plants observed had been transplanted about 2 months earlier and were seriously affected. Incidence of the disease may be slight in some years, but very extensive (more than 3,000 ha) in others.

There were several symptoms. Some plants were stunted, though the tiller number and color were normal. Other plants were normal in size, but with orange-yellow leaves and no brown spots. In some cases, there was yellowish mottling on otherwise green leaves. Tillers were open and the leaf blade made a large angle with the culm. Roots looked reasonably healthy, but root rotting occurred at later stages of growth. In individual hills, some plants showed discoloration while most others were healthy.

After transplanting, plants were normal for a month or so before the disorder started to appear. In severely affected fields almost all plants suffered from the disorder to some degree. Analysis of the plant samples did not reveal any abnormality. Many of the symptoms

*Chemist, Department of Agriculture.

were similar to those of virus-infested plants. Intensive studies by IRRI's plant pathologist (*80, 81*) have shown that the disorder is caused by a virus, the symptoms of which closely resemble those of the tungro virus in the Philippines.

INDONESIA

Indonesia consists of many islands distributed from east (141°E) to west (95°E) and from about 6°N to 11°S. The larger part of the country lies within the Southern Hemisphere. Java, Sumatra, Kalimantan, and Sulawesi are the four big islands of Indonesia. Our survey was confined to only a portion of Java.*

Efforts were made to observe "mentek," but no typical case was seen. Phosphorus deficiency was serious on latosols over a fairly wide area. In some areas phosphorus deficiency associated with a very high iron content in the plant was observed. Unusual symptoms were often observed in coastal areas. Sample sites are shown in Figure 7 and Table 22.

Data from analysis of plant and soil samples are given in Tables 23 and 24.

Phosphorus deficiency combined with iron toxicity

On a large area of latosols, phosphorus deficiency was serious. Badly affected plants did not tiller actively and were stunted. Some lower leaves were dead and others dark brown. The upper leaves were narrow, rolled, and erect. The roots were black. In milder cases, the lower leaves were reddish or yellowish and the bottom ones brown, but young leaves were green. Plants were stunted with few tillers. These symptoms, apart from the brown bottom leaves, are similar to those of phosphorus deficiency. At Sumber Bandung the local name describing this conditions is "Prekeke." The plants (Sites 1, 4, 5) were low in phosphorus. No bronzing-type iron toxicity symptoms were observed although the iron content of the plants was very high. Aluminum content was also high but manganese content was low in at least some samples (Site 1).

The area is mountainous or hilly; tea or rubber is planted on the slopes and rice in the valleys. Two or more crops of rice are grown annually if water is available. It is a common practice to harvest only the panicle and to incorporate the straw into the soil. Large amounts of iron compounds are generally deposited on the soil surface under the irrigation water. Iron toxicity is not as serious, however, probably because irrigation water is usually run continuously over the fields and drained away by small surrounding ditches.

Nitrogen deficiency is common. The latosols seem to be low in nitrogen and phosphorus and, sometimes, potassium. They have a fairly high cation exchange capacity and, except for potassium, adequate exchangeable bases. The soils are not low in reducible manganese, but their high coefficient of phosphorus absorption is probably related to the phosphorus deficiency of the plants.

Disorders in coastal alluvials ("Omo Merah," "Ama Merah")

On heavy coastal alluvials with restricted drainage, large areas were affected by a disorder (Sites 2, 3) characterized by dark-brown lower leaves which eventually died and by upper leaves which were dark green and rolled. Sometimes the seedlings failed to establish. They became brownish-yellow or had brown-spotted narrow leaves. The plants were low in phosphorus and sometimes potassium. Iron content was extremely high. Sometimes sodium content was also high, possibly indicating an influence of sea water. The symptoms seem to reflect iron toxicity induced at early stages of growth. The soils in this area may be acid sulfate soils.

*Visited in February, 1965.

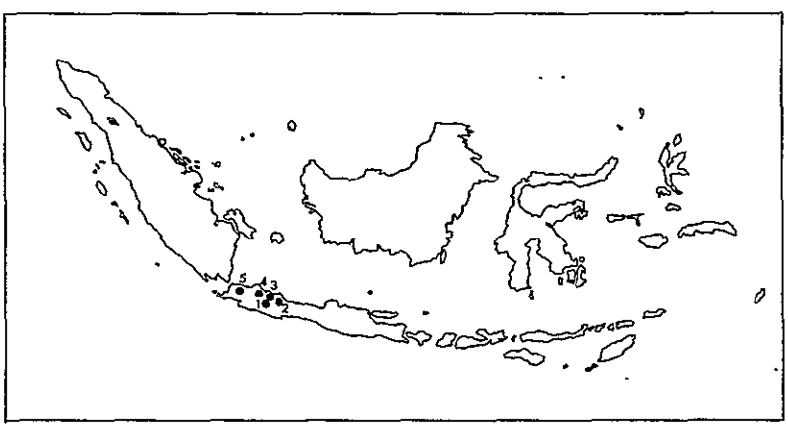

Fig. 7 . Survey sites in Indonesia.

Table 22. Sampling sites in Indonesia.

Site no.	Site	Note
1	Nagrek	Symptoms similar to P deficiency. Alluvial soil derived from lateritic material. P application corrects disorder.
2	Lohbener	Locally called "Omo Merah." Leaves yellow, narrow with brown spots. Lower dark-brown leaves die.
3	Djubleng	Locally called "Ama Merah." Upper leaves dark-green and rolled. Lower dark-brown leaves die. Area low-lying near sea. Brackish water often enters field.
4	Kosambi	P deficiency symptoms. Heavy clay soil in hilly lateritic area.
5	Sumber Bandung	Locally called "Prekeke." P deficiency symptoms. Heavy clay soil in hilly lateritic area. Internal drainage poor.

"Mentek"

The term apparently originated among farmers. Although no scientific definition of the disorder exists, "Mentek" was the name used by Dutch scientists. There seem to be many equivalent local terms in various provinces, such as "Omo Merah" and "Ama Merah" (red disease) and "Prekeke" (stunting).

The term "Mentek" appears to describe a disorder with the following symptoms. The leaves, beginning at the base, become yellow or reddish-yellow 1 to 3 weeks after transplanting and finally dry up. Growth and internode elongation are retarded, tillers assume a fan shape, and roots become black and decay. Recommended controls include draining the affected field, inter-row weeding, and application of nitrogen and phosphorus. The disease has been thought to be a result of root death caused by decomposition products under ill-drained conditions. Virus, nematodes, and potassium and phosphorus deficiencies have also been suspected. The incidence of the disease was sharply reduced when the resistant variety, Bengawan, was introduced.

Attempts to define "Mentek" by questioning local experts were unsuccessful. The answers were ambiguous. Many disorders accompanied by stunting seem to be called "Mentek," not only by farmers, but by scientists, too. Some of the examples seen could have been caused by phosphorus deficiency or iron toxicity. Under these circumstances, any conclusive statement could be misleading. There is some evidence (see Chapter 2) that some or all "Mentek" disorders are caused by virus.

Table 23. Analysis of plant samples in Java.

Site no.	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	Fe (ppm)	Mn (ppm)	Al (ppm)	SiO_2 (%)
1	0 09	2 47	0 46	0 29	0 24	1533	63	720	10 0
2	0.10	2.67	0.45	0.38	0.65	1516	313	694	9.8
3	0.15	1.79	0.47	0.49	2 88	1355	375	728	9.3
4	0 06	1 27	0 34	0.28	0.57	2590	575	789	11 0
5	0.09	2.36	0 36	0.27	0.65	1183	575	459	9.3

Table 24. Characteristics of soil samples in Java.

Site no.	pH	CEC* (meq/100 g)	Exchangeable cations (meq/100 g)				OM** (%)	Phosphorus absorption coefficient (mg/100g P_2O_5)	Active Fe (%)	Easily reducible Mn (ppm)
			Ca	Mg	K	Na				
1	5.4	33.4	12.0	10.5	0.79	0.57	6.0	1397	1.20	292
4	4.6	13.8	6.5	5.0	0.28	0.41	1.7	756	0.92	357

* Cation exchange capacity.
** Organic matter.

INDIA

The Indian subcontinent, projecting southwards into the Indian Ocean, consists of a peninsula to the south of latitude 22°N and a broad low alluvial plain, the axis of which runs east and west. The peninsula is of comparatively low elevation with a ridge of hills near the west coast from which the land slopes slowly eastwards. To the north of the peninsula is the low plateau of central India, gradually levelling to the extensive Indo-gangetic plain (alluvium of the Ganges and the Indus) which, except in the immediate vicinity of hills, is not above 240 m. To the north of this extensive plain is the lofty continuous barrier of the Himalayas.

The country* is so vast and embraces so many natural environments that our short visits, totaling about 1 month, could cover only a small portion and a limited set of conditions.

The great range of environments makes it almost impossible to give a simple account of soil distribution, but the following brief description may be helpful. For detailed information, the reader may refer to "Soils of India" by S.P. Raychaudhri and "Saline-Alkali Soils in India" by R.P. Agarwal and R.N. Gupta**.

In Kerala State, in the southwest part of the peninsula, lateritic and saline peaty soils are found. Black cotton soils or regur, and red soils or chalka, are typical of the Decan trap. Regur are black, fine-textured soils located in low-lying areas; chalka are red to grey, coarse-textured soils found in elevated areas. Both soils are generally alkaline. In Orissa State, rice is grown on lateritic soils, red soils, and alluvial soils. Calcareous and alkali soils are found in the northern part of the Indo-gangetic plain.

Nutritional disorders of rice observed by us were closely associated with the soils mentioned above. Sample sites are shown in Figure 8 and Table 25 and chemical analyses of plant and soil samples are shown in Tables 26 and 27.

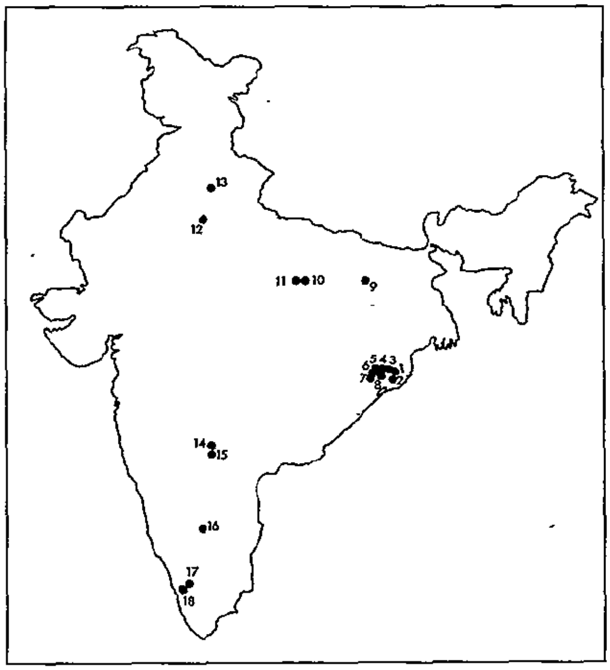

Fig. 8 . Survey sites in India.

Phosphorus deficiency

Typical phosphorus deficiency symptoms were frequently observed on lateritic, red, and black soils (Sites 5, 8, 14, 15, 16, 18). These soils and the plant samples collected from them were very low in phosphorus.

In Kerala, farmers often incorporate green leaves, especially mango leaves, into rice fields on lateritic soils. This practice could increase soil phosphorus availability. Even after flooding, typical lateritic soils remain reddish for a long period, indicating that they are difficult to reduce, possibly because of the abundance of ferric oxides related to that of organic matter.

Between Coimbatore and Trichur, there is a large area of rice on lateritic (locally called, "Chenkal Mannur," meaning red stone) soils. Plants on these soils tiller weakly and have dry, brown lower leaves and dirty-green upper leaves with a yellowish tint. The symptoms are similar to those observed on lateritic soils in West Java.

At Patanbi, we were informed that no response to phosphorus occurs at up to 90 kg/ha P_2O_5 on lateritic soils. However, if phosphatic fertilizers are applied along with about 5,600 kg/ha of green leaves or 1,680 kg/ha of lime, a marked response to phosphorus occurs. Basic slag gives a positive response at 90 kg/ha, but not at 45 kg/ha. These observations, together with the high coefficient of phosphorus absorption, suggest that on lateritic soils phosphorus availability is limited by fixation.

In Orissa State, phosphorus deficiency is common on lateritic soils. Red and black soils in the Decan trap are low in phosphorus and typical symptoms of deficiency were frequently observed.

At Rudrur farm, north of Hyderabad, a well-designed phosphorus experiment was in progress. Typical phosphorus deficiency symptoms were observed at this farm, and application of 112 kg/ha P_2O_5 was recommended.

Plant samples from "Usar" soils (solonetzic) were also low in phosphorus (Sites 10, 11).

*Visits were made in August 1966 and July 1968.

**These books are published by the Indian Council of Agricultural Research, New Delhi.

Table 25. Sampling sites in India.

Site no.	Site	Note
1	Bhubaneswar	Fe toxicity symptoms. Lateritic soil.
2	O.U.A.T. (Bhubaneswar)	Heavy planthopper attack. Lateritic soil.
3	Panigala	Fe toxicity symptoms. Lateritic soil
4	Khurda	Chalka soil (?)
5	Khuntuni	P deficiency symptoms. Lateritic soil.
6	Khuntuni	Fe toxicity. Root rot. Lateritic soil. Area low-lying with deep water.
7	Angul	Helminthosporium leaf spot present. Black soil.
8	Baladia Banda	P deficiency symptoms. Lateritic soil.
9	Arrah	Alluvial sandy soil.
10	Manoharpur	Leaves slightly chlorotic. "Usar soil" (clayey).
11	Umerha	Salt-affected. "Usar soil" (silty).
12	IARI, New Delhi	Severe chlorosis Red soil
13a	Pant Nagar	Zinc deficiency (Khaira disease). Calcareous soil.
13b	Pant Nagar	Normal plants.
14a	Rudrur	P deficiency symptoms. Regur soil.
14b	Rudrur	Brown spots P deficiency symptoms
15	Rajendranagar	P-deficient and salt-affected. Regur soil.
16	Bangalore	P-deficiency symptoms. Chalka soil
17	Mankruch	Plants stunted; lower leaves brown at death.
18	Vatanakhurissi	P deficiency symptoms. Lateritic soil.

ron toxicity

Typical symptoms of iron toxicity were observed on sandy lateritic soils at Bhubaneswar, Orissa State (Site 1). The top soil was sandy, mostly quartz, and the subsoil a yellowish-orange clay. The field was ill drained and a scum of iron compounds was observed on the surface of standing water, especially where water was percolating down from more elevated fields.

The disorder is known locally as "Mainshia." The symptoms develop about 1 month after transplanting. Brown spots develop at the tip of old leaves which eventually became completely bronzed. The intensity of the disorder increases as growth proceeds. Application of farm yard manure or ammonium sulfate aggravates the disorder but lime and urea alleviate it. Symptoms of iron toxicity were observed at two other places (Sites 3, 6) on lateritic soils in Orissa State. The affected plants were high in iron, low in phosphorus, and sometimes low in potassium.

Potassium deficiency

Though potassium deficiency is not serious at present, samples from black soils were low in potassium (Sites 14, 15).

Chlorosis of direct-seeded rice

Typical iron chlorosis was observed in a field of the Indian Agricultural Research Institute, New Delhi (Site 12). The field had been planted to rice for the first time following many years of upland crops. Wheat straw had been plowed under a few weeks before the seeds were drilled under upland conditions. After germination, the field was flooded and the first irrigation was with water that had high salt content. The soil was sandy and reddish in color even when flooded. At the time of our visit the pH of wet soil was 7.5. The chlorotic symptoms were identical with those observed on plants grown in culture solutions with high pH. The cause of the disorder may be a combination of pH and high salinity.

The color of the soil suggests that iron remained in the ferric form even under flooded conditions. The plant analysis indicates that the manganese content was low but the observed symptoms were different from those of manganese deficiency. The fairly high iron content could be attributed to soil contamination of the samples.

Salinity and alkalinity

Saline soils occur widely in coastal areas and also in low-lying inland areas that have a distinct dry season. In coastal areas salinity is often combined with acidity, but in inland areas it is combined with alkalinity.

In the coastal region of Kerala, there are large swamp areas with peaty, acidic, and brackish soils. These areas are called Kari, Pokhali, or Cole lands. In the rainy season, they are flooded by 2 to 3 meters of fresh water from surrounding rivers. In the dry season, the water level falls and is replaced by brackish water from the sea. Before planting rice, the farmers pump out the excess water, and construct high mounds upon which rice is sown. During the growing period water is repeatedly admitted and pumped out. This appears to facilitate the removal of salts from the surface soil layers. The high mounds are used to grow rice until harvest or to raise seedlings, depending on the crop seasons. This method of culture is sometimes called "Pokhali cultivation," and is probably confined to Kerala and the Netherlands.

Table 26. Analysis of plant samples in India.

Site no.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	SiO_2 (%)	Na (%)	Mn (ppm)	Fe (ppm)	Al (ppm)	Zn (ppm)
1	1.93	0.09	1.58	0.23	0.11	7.56	1.78	228	1173	307	23
2	—	—	—	—	—	—	—	—	—	—	—
3	1.49	0.08	2.77	0.47	0.10	7.44	1.99	240	1196	571	28
4	—	—	—	—	—	—	—	—	—	—	—
5	2.06	0.05	2.16	0.43	0.04	9.00	2.03	490	1840	638	46
6	1.97	0.01	2.72	0 31	0.10	12.18	1.80	609	1365	709	46
7	—	—	—	—	—	—	—	—	—	—	—
8	1.75	0.06	2.94	0.43	0.15	7.02	2.14	278	1125	359	22
9	1.30	0.07	2 84	0.29	0.16	7 50	1.99	121	1299	163	19
10	1.75	0.02	2.32	0.29	0.28	6.68	2.25	292	1702	524	12
11	1.47	0.02	3.06	0.43	0.36	6.30	2 78	116	1415	632	12
12	0.58	0.18	2.88	0 58	0.38	8 64	2 91	35	989	506	21
13a	0.26	0.06	3.32	0.48	0.31	12.80	2.97	138	735	340	7.7
13b	1.77	0.20	2.28	0 55	0.51	7.00	2 59	219	988	211	17
14a	1.92	0.02	0.98	0 46	0.91	6.10	2 97	117	818	419	12
14b	1.60	*	1.68	0.36	0.20	7.98	2 48	112	1424	578	—
15	1.39	0.09	0.86	0.36	0.20	7 74	1 68	98	1196	292	29
16	2.43	0.19	1.65	0.17	0.09	10.08	1.62	105	1587	415	25
17	2 57	0.17	1 65	0.24	0.10	12 64	1.79	236	806	687	27
18	2.36	0.10	2.04	0.22	0.15	7.78	1.63	26	988	386	20

*Trace.

Table 27. Some properties of soil samples in India.

Site no	pH (H_2O)	CEC* (meq/100 g)	Exchangeable cations (meq/100 g)				OM** (%)	Phosphorus absorption coefficient (mg/100 g P_2O_5)	Available phosphorus (ppm)	Active iron (%)
			Ca	Mg	K	Na				
1***	5.8	3.2	0.86	0 28	0.05	0.20	1.83	2668	†	0.17
1****	5 2	7.8	0.76	0.58	0.11	0.22	0.76	1644	†	0 82
2	5.8	5.0	2.99	0.94	0.51	0.37	1.24	230	5.2	0.25
3	5.5	11.5	6.26	2.09	0.27	0.44	1.48	1374	1.0	0.45
4	5.3	12.1	5 73	2.28	0.58	0 55	1 59	920	†	0.39
5	5.3	13.2	7.12	3.18	0.22	0.43	1.45	1242	†	0.51
6	5 4	15.9	7.70	4.80	0.47	0.65	2.41	1104	†	0.73
7	7.8	38.9	55.18	12.62	1.21	1.06	1.97	2300	†	0.34
8	7 1	12.7	10.58	4.68	0.38	0.57	1.21	1236	†	0.31
9	7.0	16 6	9.86	5.76	0 70	1.63	0.93	1104	†	0 40
10	10.4	8.9	14.54	1.20	0.67	21.43	0.14	92	†	0 07
11	9.7	3 3	5 28	1.80	0 19	2.98	0 24	46	†	0 06
12	8.3	8.4	13.22	3 86	0.34	0.90	0.76	322	†	0 11
13	8.3	12.4	25.24	8 66	0.35	0 70	2.21	1334	1 3	0.15
14	8.3	30 0	30.30	12.98	0.58	1.95	1.45	1932	†	0.24
15	7.8	35.9	35.94	15.74	0.87	2.37	1.88	1840	†	0.49
16	4 8	3.8	0.72	0.48	0.08	0.43	1.03	1414	†	0.27
17	5.0	6.1	0.96	1.44	0.10	0 43	2.72	1322	†	0.34
18	5.1	6.8	0.72	0.96	0.20	0.43	2.98	1196	1 3	0.22

* Cation exchange capacity
** Organic matter.
*** Topsoil.
**** Subsoil.
†Trace.

Table 28. Effects of zinc application on dry weight and zinc content of the rice plant on Pant Nagar soil.

Zn added	Dry weight (g)	Zn content (ppm)
0	1.78	8
40	5.71	151

On the alluvial soils of the Ganges in Bihar and Uttar Pradesh, salinity is combined with alkalinity. The soils often contain Kankar (calcium carbonate concretions) at some depth in the profile. In depressed portions of the landscape black spots called "Karail" occur. Farmers regard them as good rice soils. At Manoharpur near Moghalsarai, there are "solonetz-like" soils, known locally as "Usar." White crystalline salts are deposited on the surface in the dry season. The soils are characterized by high pH, low organic matter, and high sodium (Sites 10, 11).

We were told that when upland crops are grown for a few years, salt concentration in the soil increases to such a level that no crop can be grown. In these circumstances, the fields are enclosed by levees and water allowed to stand for 1 or 2 years to leach the salts before rice is planted. After a few crops of rice, the salinity level falls and upland crops are grown. This is the general method of amelioration of Usar soils.

Rice grows unevenly in these fields. Where salt accumulation is high the plants are stunted and chlorotic.

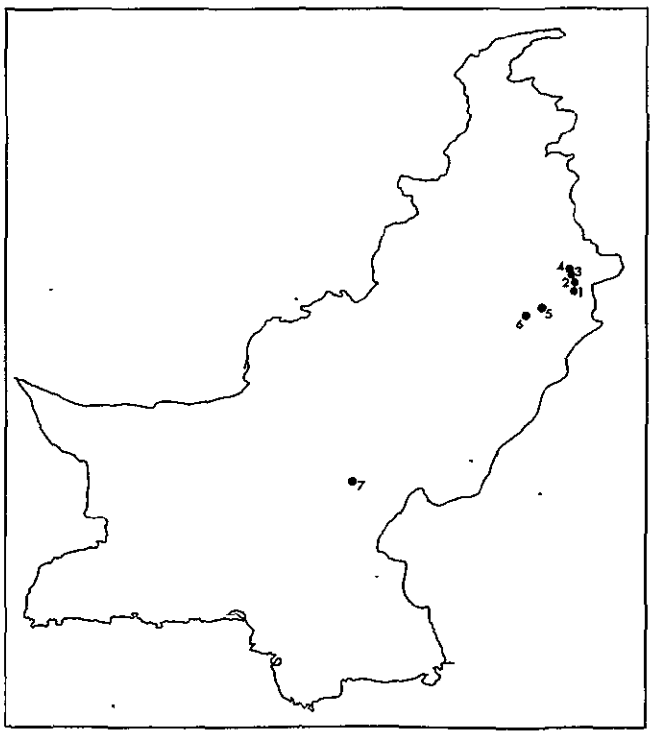

Fig. 9. Survey sites in West Pakistan.

Generally, the plants are chlorotic in the early stages of growth but gradually recover and produce fairly good yields (about 3 metric tons/ha). Special varieties are used in this area.

In Rajendranagar, Hyderabad, rice exhibits severe iron chlorosis when grown in upland nurseries but not in flooded nurseries. This is a common observation on alkaline soils.

Zinc deficiency

In Tarai District, Uttar Pradesh, land was reclaimed for rice in 1955 and about 16,000 hectares are now under cultivation. A few years after reclamation, a disorder, known locally as "Khaira" (meaning reddish-brown color), became a problem. Corn also suffers from a similar abnormality in this region, but sugar cane and wheat do not.

Older leaves become reddish brown about 2 weeks after transplanting, the plants are stunted, and the roots are sparse and brown in color. The bases of actively growing leaves are chlorotic. The symptoms are more apparent in sunny weather. Six weeks after transplanting, the plants usually recover to some extent. The disorder is more serious in low-lying parts of fields and affected areas have a high water table during the rainy season. The soils are calcareous with high pH, relatively high organic matter, and low available phosphorus. The plant sample analyzed was very low in zinc (Site 13). Dr. Nene of Uttar Pradesh Agricultural University has demonstrated a beneficial effect from foliar spraying of affected plants with zinc sulfate.

To confirm zinc deficiency in the Pant Nagar soil, rice was grown with and without added zinc in the greenhouse. About 3 weeks after transplanting, plants without added zinc developed interveinal chlorosis, brown streaks, and marginal leaf scorch. Growth was stunted. As shown in Table 28, the addition of a small amount of zinc resulted in a remarkable increase in dry weight and this was associated with increased zinc content.

The visible symptoms, plant analysis, and the greenhouse and field experiments all support the contention that "Khaira" is an example of zinc deficiency of rice in the field.

WEST PAKISTAN

West Pakistan* is located north of the Tropic of Cancer, between about 24°N and 37°N. It is essentially a desert area with only 50 to 75 mm of rainfall annually in the southern region and about 500 mm annually in the central region. The climate is quite different from mon-

*Visits were made in September 1967 and July-August 1968. We visited East Pakistan before proceeding to West Pakistan in 1967 and visited such places as Mymensingh, Dacca, and Comilla Under the prevailing conditions in East Pakistan (over-flooding, pests, and diseases), it was difficult to identify nutritional problems, and therefore the observations made have been excluded from this report

Table 29. Sampling sites in West Pakistan.

Site no.	Site	Note
1	Kala Shah Kaku	Zinc deficiency symptoms. Calcareous Soil.
2	Kamoke	Zinc deficiency symptoms Calcareous soil.
3	Gurjanwala	Brown spots about 15 days after transplanting, none at later stages. Calcareous soil.
4	Gujranwala	Zinc deficiency symptoms. Calcareous soil.
5	Manga	Brown spots 20 to 25 days after transplanting, none at later stages. Calcareous soil.
6	Bhai Pheru	Brownish-purple spots, tip withering and midrib chlorosis. Calcareous soil.
7	Dokri	Calcareous soil. Some fields salt-affected.

soon climates in several ways: Temperatures are higher in the summer crop season (up to 51.7 C); the rainfall is about 50 to 500 mm per year; and there is abundant sunshine.

The soils are generally calcareous with pH values ranging from 7.5 to 9.5 and there are some salinity problems. Irrigation canals, which are relatively well distributed, supply water of excellent quality but its use is restricted and it is expensive. A water sample taken from the canal between Hyderabad and Karachi had an EC value of 330 micro-mhos/cm and 6 ppm of potassium. Underground water is generally poor in quality because of high electric conductance.

Sampling sites are shown in Figure 9 and Table 29, and chemical analyses of plants and soils in Tables, 30 and 31.

Zinc deficiency

In some fields at Kala Shah Kaku Rice Research Station, Lahore (Site 1), rice plants were stunted and exhibited leaf browning. The disorder, locally known as "Hadda", is sometimes referred to as "bronzing" because of the brown discoloration of the leaves.

The disorder has been known for about 20 years, and has reportedly become more apparent since the introduction of improved IRRI varieties in 1964, especially when these have been planted with adequate fertilizers.

The plants were severely affected by the disorder when they were dark green and presumably well fertilized, but less affected when yellow and presumably deficient in nitrogen. The importance of the disorder is demonstrated in Table 32. Application of fertilizer does not increase yield at Kala Shah Kaku Rice Station where the disorder is serious, but a marked response to fertilizer application is obtained at Dokri Rice Station where no such problem is present.

During our visit to the northern part of West Pakistan, we frequently observed symptoms similar to those at Kala Shah Kaku (Sites 2, 3, 4, 5, 6). The following is a summary of our observations.

Table 30. Analysis of plant samples in West Pakistan.

Site no.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)	SiO_2 (%)	Fe (ppm)	Mn (ppm)	Al (ppm)	Zn (ppm)
1	2.44	0.25	3.30	0 14	0.27	0 70	13 4	954	558	468	9.8
2	1.93	0.19	2.90	0 23	0 47	0.50	11 8	893	743	510	11
3	1.77	0.19	1.95	0.09	0 24	0.35	8 1	254	410	165	18
4	2.73	0.20	2.40	0 11	0 27	1.33	11.4	1050	145	523	14
5	2.01	0.19	2 58	0 11	0 36	2 00	15 6	683	312	374	11
6	2.67	0.21	3.35	0.14	0.33	0 25	12 6	707	308	425	12

Table 31. Characteristics of soil samples in West Pakistan.

Site no.	pH (H_2O)	CEC* (meq/100 g)	Exchangeable cations (meq/100 g)**				OM*** (%)	Phosphorus absorption coefficient (mg/100 g P_2O_5)	Available phosphorus† (ppm)	Active iron (%)
			Ca	Mg	K	Na				
1	7.9	11 4	31 60	3.06	0.45	1.03	1.69	598	4	0.18
5	8 6	5 2	28.88	3 44	0.58	0.33	0 43	874	3	0 07
6	8.6	8 9	11.00	30.47	0.80	1.03	0.67	1380	6	0 10
7	8.5	12 3	48.69	4.59	0.45	0.27	1 19	1702	1	0.27

* Cation exchange capacity
** Not corrected for free carbonate.
*** Organic matter.
† By Olsen's method

Table 32. **Fertilizer trial on IR8 at two locations in West Pakistan, 1966***.

Fertilizer**	Grain yield (kg/ha)	
	Dokri	Kala Shah Kaku
0- 0- 0	5610	5735
0-45-45	7140	5476
34-45-45	8770	5153
67-45-45	9240	5569
101-45-45	9250	4903
134-45-45	10270	4936

* Adapted from Annual Progress Report, 1966, Accelerated Rice Research Program of West Pakistan
** kg of N, P_2O_5 and K_2O per hectare

1. Brown streaks and blotches start to appear, beginning on lower leaves, about 3 weeks after transplanting.
2. Affected plants usually recover later but those severely affected die.
3. The disorder appears in alkaline soils in the first year of reclamation.
4. Heavy fertilizer application aggravates the disorder but drainage alleviates it.

From visual symptoms and soil conditions, we suspected zinc deficiency. Incidentally, we observed the typical zinc deficiency symptoms of "little leaf" and interveinal chlorosis on a citrus tree near an affected rice field.

Chemical analysis disclosed very low zinc content in the plant samples collected at Kala Shah Kaku Rice Station and its vicinity.

Following the chemical analysis, a greenhouse study was made of the effect on rice growth of adding zinc to Kala Shah Kaku soil. Two weeks after transplanting, the plants started to show interveinal chlorosis of the upper leaves, followed by brown spots on the lower leaves. Growth was stunted. As shown in Table 33, when zinc was not added, growth was poor and the plants had very low zinc content. When small amounts of zinc were added, normal growth occurred and was associated with increased zinc content of the plants. All the above indicates that the disorder is caused by zinc deficiency.

Salinity problem

Salinity was frequently seen in some of the fields at Dokri Rice Station (Site 7) and its neighborhood.

Table 33. Effects of zinc application on dry weight and zinc content of the rice plant on Kala Shah Kaku soil.

Zn added (ppm)	Dry weight (g)	Zn content (ppm)
0	1 02	9
8	2.87	23

Fig. 10. Survey sites in Ceylon.

The incidence of injury was characteristically patchy, indicating the importance of slight changes in elevation.

Phosphorus and potassium status

Phosphorus deficiency is a problem at Dokri (Site 7). A greenhouse experiment with Dokri soil demonstrated that phosphorus but not potassium was limiting rice growth (Ref. Table 32). The soil had a high pH and a high coefficient of phosphorus absorption, indicating low availability of phosphorus.

Potassium content of plant samples was relatively high. In addition, the soil potassium status and the potassium content of the irrigation water suggested that the plants would be well supplied.

CEYLON

Geologically, Ceylon is a detached portion of the South India plateau, the Decan, one of the oldest land masses in the world. The island is pear-shaped and lies between about 6°N and 10°N.

The southwestern part of the island is a wet zone and receives rain from both the southwest monsoon (April to October) and the northeast (November to January) monsoon. The northern plains and east coast areas, however, are in a dry zone and receive rain only during the northeast monsoon season.

The area covered by our visit* included the hilly area in the wet zone. Sampling sites are shown in Figure 10 and Table 34. The results of chemical analyses of plant and soil samples are shown in Tables 35 and 36. Nutritional disorders are largely restricted to the wet zone; in the dry zone, soil problems appear to be less serious.

*Visited July 3-12, 1965.

Table 34. Sampling sites in Ceylon.

Site no.	Site	Note
1	Pussellawa	Fe toxicity symptoms.
2	Pussellawa	Orange-yellow leaf tips. Roots red.
3	Bombuwela	Growth extremely poor. Upper leaves brown. Few brown spots. K deficiency suspected.
4	Bombuwela	—
5	Bombuwela	Fe toxicity symptoms. Old roots dead and new roots developing from crown. Area adjacent to rubber plantation.
6	Bombuwela	Fe toxicity symptoms.
7	Karapincha	K deficiency symptoms
8	Karapincha	Orange-yellowish leaves.
9	Karapincha	Fe toxicity symptoms.

"Bronzing" was common in the wet zone, although the area of observed typical bronzing was limited. Many cases of potassium or phosphorus deficiency were observed. Judged from the distribution of bronzing and nutrient deficiencies and the gradual changes from one to the other, deficiencies of the nutrients and bronzing seem interrelated.

In the wet zone, acidic rocks dominate an old geological formation and strong laterization has taken place. At high elevations the lateritic hills are planted to tea; rubber is planted on the lower slopes and rice in the valleys (Sites 1, 2, 7, 8, 9). At high elevations the soils are low in practically all nutrients. At lower elevations rubber is grown on the lateritic hills and rice in the lowlands (Sites 3, 4, 5, 6). The soils are generally sandy (silica sand) and low in several nutrients, including manganese. In some places drainage appears to be a problem and the soils are boggy. Rice growing on the almost pure silica sand suffer from several nutrient deficiencies. In regions of lowest elevation, where the formation is alluvial, coconuts are grown on the higher parts and rice on the lower. The soils are mostly coarse-textured, rather low in pH, and very low in cation exchange capacity and exchangeable bases.

"Bronzing"

This occurs on sandy soils at the base of lateritic hills. The symptoms were more or less identical with those of iron toxicity produced in water culture, and the iron content of bronzed plants was high enough to be toxic.

The plants were generally low in phosphorus, potassium, magnesium, manganese, and sometimes calcium. This general malnutrition could also be in part responsible for bronzing. Excess iron in combination with general malnutrition appears to cause iron toxicity symptoms.

Rice plants were grown in a Bombuwela sandy soil

Table 35. Analysis of plant samples in Ceylon.

Site no.	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Al (ppm)	SiO_2 (%)
1	1.31	0.16	0.50	0 18	0 12	760	562	177	7.75
2	1.35	0.16	1.80	0.42	0.25	1490	691	500	10.75
3	2.61	0.07	0.65	0.11	0.09	300	38	207	5.03
4	1.58	0.15	0.90	0.50	0.17	1040	*	253	5.02
5	1.72	0 17	0.80	0.23	0.17	1610	130	306	3.87
6	1 88	0 32	0.80	0.47	0.13	950	66	289	4.38
7	1.54	0 21	0 80	0.40	0.22	1250	149	354	6 53
8	0.78	0 07	1.90	0.13	0.09	560	281	279	6.88
9	0.90	0 21	0.75	0.11	0.06	600	249	156	6 68

*Trace

Table 36. Some characteristics of soil samples in Ceylon.

Site no	pH	CEC* (meq/100 g)	Exchangeable cations (meq/100 g)				OM** (%)	Phosphorus absorption coefficient (mg/100 g P_2O_5)	Active Fe (%)	Easily reducible Mn (ppm)
			Ca	Mg	K	Na				
1	5 18	9.5	2 0	1.2	0.17	0.26	4.0	802	0.508	8
5	5.15	3.6	2.0	1.2	0.15	0.17	2.3	229	0.159	0 8
7	5.15	5.2	1.5	1 2	0.15	0.17	2.9	344	0.280	23

* Cation exchange capacity
** Organic matter.

Table 37. Result of a sand culture experiment using a Bombuwela sandy soil with various culture solutions.

Treatment	Dry weight	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Mn (ppm)	Symptoms
		Element content of plant						
Complete	1.68	0.26	2.59	0.32	0.36	410	93	Normal
Minus P	0.74	0.12	2.83	0 36	0.31	673	67	P deficiency
Minus K	0.47	0.28	0.45	0.28	0.51	2350	57	Bronzing
Minus Ca	1.11	0.20	2.13	0.27	0.28	765	40	Normal
Minus Mg	1.13	0.24	2.38	0.36	0 23	762	62	Normal
Minus Mn	0.67	0.26	3.63	0.54	0.46	1140	17	Mn deficiency

with various culture solutions (Table 37). Bronzing symptoms developed in a potassium-deficient solution; the potassium content of the plant was very low, and the iron content very high. In a phosphorus-deficient solution, typical phosphorus deficiency symptoms developed, and, in a manganese-deficient solution, manganese deficiency symptoms developed.

We concluded that the soils are low in several elements. Bronzing is caused by high iron content associated with low potassium level in the soil.

Murungkayan 302 is reported to be susceptible to bronzing. After H-4 became popular among farmers, the bronzing problem decreased, although, on soil which produces bronzing in Murungkayan 302, H-4 is not healthy; H-4 shows no bronzing symptoms, but growth is stunted and leaf tips are orange.

"Bronzing" is not easily defined. If it is defined as the development of bronze color in spots or covering the leaves, it is not common in H-4. If it is defined, however, as a growth disturbance caused by the factor (or factors) for "bronzing" symptoms in some varieties, then it frequently occurs even in H-4.

If the first definition is accepted, it is a minor problem of rice in Ceylon because the area affected is limited. However, if "bronzing" is used to describe a disturbance of growth due to soil problems, especially in relation to iron and potassium, it is a major impediment to rice production.

General nutrient deficiencies

Rice plants in both the hilly and the low areas in the wet zone were always low in potassium and phosphorus and sometimes in manganese, magnesium, etc. They were often high in iron. Potassium and phosphorus deficiency symptoms were common.

Leaf color was sometimes pale yellow, indicating acute nitrogen deficiency. Otherwise, leaves were generally green with a rusty tint which seemed to indicate deficiencies of potassium or phosphorus or some other nutrients. Healthy green plants were rare.

These observations strongly suggest a general malnutrition of rice in this part of Ceylon. "Bronzing" is only a visible extreme case, but the basic cause of "bronzing" may be generally present.

Causes of disorders

PHOSPHORUS DEFICIENCY

Phosphorus deficiency is commonly observed on lateritic soils, black cotton or regur soils, red or chalka soils, Ando soils, and some acid soils.

The deficiency is primarily caused by the low capability of the soil to supply phosphorus. The high coefficient of phosphorus absorption of Ando soils is also important.

Phosphorus-deficient plants are usually characterized by a dark-green leaf color, erect leaf habit, and reduced tillering. However, when the deficiency is combined with nitrogen deficiency, leaves become pale green. This condition was most frequently observed on phosphorus-deficient plants during the survey.

Under these circumstances, plant tissue analysis gives a more definite answer. When the phosphorus content of plant tissues during vegetative growth is less than 0.2 percent P, phosphorus deficiency may be suspected, and when less than 0.1 percent, a deficiency is very probable.

Since phosphorus deficiency occurs in soils of low or high pH, it is frequently associated with other kinds of disorders, such as iron toxicity on acid soils and iron deficiency or salinity in alkaline soils. These problems will be discussed later.

Several materials are available for phosphate fertilization. Superphosphate, concentrated superphosphate, rock phosphate, and fused phosphate are most common. Choice of the chemical form of phosphatic fertilizer depends on the nature of the soil to which the phosphate is to be applied. In general, superphosphate or concentrated superphosphate is suitable. On acidic soils that have a high coefficient of phosphorus absorption, fused phosphate may be used. The optimum rate of application also depends on the nature of the soil and other factors such as nitrogen application.

For Ando soils in the northern part of Honshu in Japan, the optimum amount is estimated to be about 200 kg/ha P_2O_5. This corresponds to about 1 percent of the phosphorus absorption coefficient of the soil. These soils have a very high phosphorus absorption coefficient, about 2,500 mg/100 g P_2O_5 soil, and a relatively low pH of 5.6 to 5.7 (*31*).

In calcareous soils, at Rajendranagar, India, an adequate amount of phosphorus is considered to be about 80 to 100 kg/ha P_2O_5 (*35*). At Dokri, West Pakistan, about 45 kg/ha P_2O_5 seems enough to produce about 10 tons of grain per hectare (Table 32).

POTASSIUM DEFICIENCY

Low potassium content was frequently found in plants growing on lateritic soils, calcareous soils, and some sandy soils. It was also associated with iron toxicity which was common on acid lateritic soils and acid sulfate soils.

In general, nitrogen or phosphorus deficiency and iron toxicity symptoms were more pronounced than potassium deficiency symptoms. Potassium deficiency was also frequently accompanied by *Helminthosporium* leaf spots.

Incidence of *Helminthosporium* leaf spots is closely associated with "Akiochi" in Japan and Korea. This association occurs on sandy soils with excessive internal drainage. But in Bohol, Philippines, we observed this association on a calcareous soil with poor internal drainage.

One of the main causes of potassium deficiency is the low capability of the soil to supply potassium, for which exchangeable potassium content appears to be a good measure. This may be particularly true in rain-fed fields where the soil is the only source of potassium, although it may not always be true for irrigated fields where some potassium comes from the irrigation water.

It has been well established that hydrogen sulfides, organic acids, carbon dioxide, and a large excess of ferrous iron retard potassium uptake by the rice plant (*8, 15, 17, 60, 61, 71, 95, 125*). A large excess of sodium or calcium ions in the soil solution may also retard, potassium absorption.

Two or more factors are probably often associated under natural conditions. In a calcareous soil in Bohol, Philippines, for example, potassium deficiency appears to be caused by a low content of exchangeable potassium in the soil, possibly in combination with high content of organic acids, and calcium and bicarbonate ions.

Potassium chloride and potassium sulfate are commonly available for potash fertilization. Field experiments conducted in Bohol, Philippines, show that 50 kg/ha K_2O can be considered an adequate dose and that potassium chloride, potassium sulfate, potassium metaphosphate, and potassium silicate are equally effective (*65*).

ZINC DEFICIENCY

Until very recently, field deficiencies of zinc in rice were not known, although such deficiencies are often observed in upland crops such as corn, citrus, and cauliflower. Records of zinc deficiency of rice in Pant Nagar, U.P., India; Kala Shah Kaku, Lahore, West Pakistan; Cebu, Philippines; and Chiba, Japan have provided new information on nutritional disorders of rice.

"Akagare Type II" has long been considered to be caused by organic acids, soluble ferrous iron, and hydrogen sulfides in combination with potassium deficiency. Our survey, however, showed that this disorder, at least on certain soils, is very likely to be zinc deficiency. The "Khaira" disease of India, "Hadda" of West Pakistan, "Taya-Taya" of the Philippines, and "Akagare Type II" all have similar visible symptoms, all are characterized by low zinc contents in the plant, and all occur on soils with high pH. Visible symptoms of iron toxicity and zinc deficiency are similar in some respects but it is unlikely that ferrous iron would cause the disorder on calcareous soils with high pH. Actually, "Hadda" in West Pakistan is sometimes referred to as bronzing (iron toxicity). However, iron toxicity occurs on acid soils and zinc deficiency on alkaline soils, thus emphasizing the importance of soil pH in diagnosing nutritional disorders.

There is a similarity between zinc-deficient rice soils. The deficiency is common on calcareous soils of high pH, suggesting that fixation of zinc in calcareous soils is a primary cause of the deficiency. The critical levels of zinc in the rice plant associated with deficiency symptoms are similar for rice and other crops (*127*). For rice it is about 10 to 15 ppm (*44, 144*); for beans 10 to 22 ppm; for tomato 12 to 17 ppm; for corn 15 ppm; and for tung tree 10 to 26 ppm. These data indicate that the internal requirement of rice for zinc is not necessarily low in comparison with that of upland crops. The incidence of zinc deficiency in rice should therefore be closely related to soil factors which are of course dissimilar for rice and other crops.

A pot experiment demonstrated that addition of cellulose accentuates zinc deficiency in rice, suggesting that soil reduction is also related to the deficiency (*144*). This finding agrees with field observations in Kala Shah Kaku, West Pakistan, that drainage alleviates zinc deficiency.

It has also been demonstrated that zinc is immobilized in roots in the presence of a large excess of bicarbonate ion (*143*). This may be part of the reason that zinc deficiency occurs at early stages of growth in calcareous soils. In submerged soils, particularly when organic matter is applied, abundant carbon dioxide is produced during the early period of submergence and, since the soil is alkaline, is converted to the bicarbonate ion.

Still another possibility exists. Under reductive conditions zinc may be combined with hydrogen sulfide to form zinc sulfide with extremely low solubility. However, the value of the solubility product of cuprous sulfide is lower than that of zinc sulfide. Therefore, from the viewpoint of solubility product, copper deficiency is more likely than zinc deficiency. These considerations indicate that critical studies are required to introduce the concept of solubility product into discussions of the causes of zinc deficiency.

There are some other aspects concerning the comparison between zinc and copper. The requirement of rice for copper is much less than for zinc (See Table 1). Copper may form complexes with amino acids which could be readily available to the plant.

During the survey, we saw rice growing on calcareous soils in many locations, but we saw zinc deficiency in only a few. Studies are needed on soil factors associated with zinc deficiency in calcareous soils. Such studies are vital if rice growing is to be extended to arid areas where soils are more or less calcareous.

Several methods have proved to be effective in correcting zinc deficiency: dipping seedling roots in 1 percent zinc oxide suspension before transplanting, application of zinc sulfate to the nursery bed, foliar spray of 0.5 percent zinc sulfate solution, and application of zinc sulfate to the field (*143*).

IRON DEFICIENCY

Iron deficiency observed during the survey is classified as being caused by:

1) High pH of alkali soils under submerged conditions;
2) High pH of calcareous soils under upland conditions; or
3) Inadequate soil reduction under submerged conditions.

Rice growing in alkali soils in the northern part of India was showing chlorosis at early stages of growth. According to the local expert, the chlorosis usually disappears about 1 month after transplanting. Under submerged conditions, the pH of the soil approaches neutrality no matter what the pH is when the soil is air-dried. In high-pH soils, the time required to lower the pH may be largely determined by organic matter content. Presubmergence or application of organic matter should alleviate the chlorosis under these circumstances.

If, for any reason, the pH of submerged soils remains high, iron deficiency occurs. When a water-cultured rice plant is subjected to a high pH, the new leaves commonly become chlorotic (*120*). The appearance of iron deficiency in rice at high pH can be explained by the low solubility of iron in the rooting medium (*88*), by fast oxidation of ferrous iron, by immobilization in the roots or by various combinations of the three (*110, 120*).

When rice is grown on a calcareous soil under both upland and submerged conditions, upland plants often show iron deficiency while lowland plants do not. This observation can be explained by the kinetics of soil pH under submerged conditions (*90*).

According to Okajima*, iron chlorosis of rice on upland calcareous soils at Rajendranagar, India can be corrected by direct injection of sulfuric acid into the rhizosphere. Application of organic matter or iron chelates does not correct the chlorosis as effectively as the sulfuric acid injection.

Application of sulfuric acid or ferric sulfate is reported to be effective in correcting chlorosis on sodic soils in California and on calcareous soils in Arkansas, U.S.A. (*54, 85*). It has also been shown that application of sulfuric acid is effective in curing "Murenae," a disorder which occurs in frame nurseries in Hokkaido, Japan (*70*).

The chlorosis observed at the Indian Agricultural Research Institute was a case of iron deficiency caused by inadequate soil reduction, probably combined with high salinity. The field had been planted to rice for the first time after many years of upland crops. The soil retained its brown color even under submerged conditions, indicating that reduction had not developed appreciably and that iron availability was low. Direct seeding could aggravate the problem because the younger the plant is, the higher the oxidizing power of rice roots. Iron deficiency under these circumstances may be corrected by applying organic matter.

In general, iron deficiency of rice does not appear to be a serious problem in calcareous soils if they contain some organic matter and if rice is grown under submerged conditions. It will become a problem, however, with upland rice.

MANGANESE DEFICIENCY

During the survey, a plant's managanese content approaching the lower critical value was found in a few places: for example, in some "bronzing" plants in Ceylon and Malaya, and in some plants with low phos-

*Okajima, H., physiologist, AICRIP, Rajendranagar, Hyderabad, India. Personal communication.

phorus but high iron in Java. Low manganese content was also common in plants from the "Akiochi" areas in Korea and Japan. Even so, we saw no typical manganese deficiency symptoms in our survey.

Manganese deficiency in upland rice has frequently been reported. However, because manganese concentration increases in the soil solution under flooded conditions, a deficiency in lowland rice is less likely.

Nevertheless, plants developed manganese deficiency symptoms when grown in a manganese-deficient culture solution with the Bombuwela sandy soil on which "bronzing" occurs. Manganese deficiency on such soils is therefore possible.

Low plant manganese content, such as that recorded in Nagrek, Java, could have been due to a high iron level in the soil. Iron and manganese interact; a high level of iron retards manganese uptake (*119*).

Manganese level is frequently low in highly weathered lateritic and degraded paddy soils ("Akiochi" soils). The iron concentration in the soil solution of such soils usually increases abruptly after submergence and iron toxicity may develop. Thus, low plant manganese content may accompany iron toxicity. A low manganese level in the soil *per se* may not cause a nutritional disorder (manganese deficiency), but such a condition is often associated with a low level of bases, including potassium, calcium, or magnesium. These soils have low pH and their capacity to buffer the lowering of Eh upon submergence is weak. These features tend to induce iron toxicity.

It has also been reported that hydrogen sulfide in the growth media retards the uptake of manganese (*9, 60, 61, 62*). Partly for this reason, plants suffering from "Akiochi" are often low in manganese (*30, 57, 103*), and such plants are reported to be susceptible to *Helminthosporium* leaf spot (*15, 40, 57*).

Thus, although manganese deficiency is not a serious problem in lowland rice, if the plant manganese content is critically low, nutritional disorders may be suspected.

LOW SILICA CONTENT

Silica is considered important in the resistance of rice to diseases and insects. Moreover, if the silica content in the rice straw is low, leaves are droopy and mutual shading may be greater (*45, 146*). Thus, for high yield with heavy fertilizer application, the silica content of the straw should be above 10 percent (*32, 146*).

Rice plants suffering from certain nutritional disorders such as "Akiochi" or "bronzing" are often low in silica. Low silica content *per se* may not be the direct cause of these disorders. Silica is one of the most susceptible elements to leaching, and the level of soluble silica in the soil can be a measure of the degree of leaching. A soil that is high in soluble silica probably is high in other nutrient elements, and *vice versa*. Thus, plant silica content may be used as an indicator of the nutrient status of the plant, except on volcanic ash soils, since some of these are high in soluble silica but low in other nutrients such as phosphorus, calcium, and magnesium.

When rice plants are low in silica, applying materials containing silica increases the grain yield. This positive response can be attributed to the increased supply of silica and the increased supply of bases such as calcium and magnesium (*77, 101*).

Various kinds of silicate slags are available from metal refining plants. The major constituents of these slags are silica and calcium or magnesium. About 1 to 3 metric tons of slag is usually recommended for alleviation of "Akiochi" in Japan (*141*). Rice straw, hulls, and their ashes are also good sources of silica.

IRON TOXICITY

The iron concentration in the soil solution is high when a soil is reduced under submerged conditions. This is particularly so when the soil has low pH and high organic matter content and is low in active iron or reducible manganese.

The symptoms of "bronzing" are many tiny brown spots on green leaves which start from the tips and develop into a general browning of the leaf blades, followed by the death of lower leaves which, by this time, are brown. In some varieties leaves become orange-yellow from the tips and later dry up. These symptoms are the same as those of iron toxicity developed in water culture by increasing the iron level at certain stages of growth, especially the later stages. We therefore considered "bronzing" to be caused by iron toxicity.

The iron content is usually high in plants showing "bronzing," but not always so high. Even in water culture it is difficult to determine a critical iron content at which typical "bronzing" symptoms appear (*122*). The critical iron content is greatly influenced by the age of the plant, its nutritional status, and the process by which the iron concentration in the growth media is increased. Consequently, diagnosis of iron toxicity by the iron content of the plant cannot be done easily.

An interaction between iron and potassium is quite apparent. "Bronzing" plants are often low in potassium, and potassium deficiency accelerates the development of "bronzing" symptoms.

A low level of potassium in the soil is generally associated with a low level of other bases and a low pH. The latter causes a high iron concentration in the soil solution.

"Akagare Type I" is remedied by the application of potassium and the disorder is therefore considered to be potassium deficiency. However, plants suffering from "Akagare Type I" are generally high in iron content. Thus it seems more appropriate to regard the disorder as being caused by an imbalance between iron and potassium. Even at a high level of potassium, "Akagare Type I" is possible if the soil solution has an extremely high level of iron. At a low potassium level, iron toxicity is more likely to develop.

Are "bronzing" and "Akagare Type I" the same disorder? Although a firm conclusion is not possible at present, we believe that these disorders may have similar causes and that the difference in symptoms is due, at least partly, to varietal difference.

Plants deficient in phosphorus on latosols or other soils high in active iron frequently have very high iron content, especially if the soils contain a high level of organic matter. When the iron concentration in the growth media is very high from the start of growth, the rice plant shows symptoms rather similar to those of phosphorus deficiency. Under such conditions in the growth media, the concentration of phosphorus in the soil solution is very low because of high phosphorus fixation by the soil. As a result, symptoms of phosphorus deficiency develop and are combined with those of iron toxicity. The symptoms are stunted growth, extremely limited tillering, narrow leaves, dark-green upper leaves, and dark-brown, rolled, dried lower leaves.

Alleviation of "bronzing" in Ceylon has been studied extensively (*33*, *78*, *79*, *87*). Suggested measures are application of lime, mainly for boggy soils; application of compost, mainly for sandy soils; incorporation of peaty or boggy soils into sandy soils; application of urea instead of ammonium sulfate; application of phosphorus and potash; drainage or continuous irrigation-drainage; and use of resistant varieties.

Iron toxicity is also a problem in acid sulfate soils. When dry, these soils have low pH which leads to iron toxicity after submergence. The toxicity is particularly severe when the soil is completely dried before submergence. After the soil has been submerged for some time, the pH rises and, as a result, the iron toxicity decreases.

These chemical changes occurring in acid sulfate soils may explain why repeated transplanting is customary for good establishment in some parts of Malaysia and why farmers have experienced severe iron toxicity after a long drought in some parts of Malaysia and the Philippines.

Improvement of acid sulfate soils is one of the most important soil amelioration problems. As described in the second chapter, several measures have been suggested but, in addition, phosphate application is usually necessary. Economically it may not be advisable to attempt to improve extremely acid sulfate soils. In any case, it would be advisable to first conduct a small-scale field experiment to determine the feasibility of reclamation.

ALUMINUM TOXICITY

Aluminum toxicity is regarded as one of the major causes of nutritional disorders of upland crops on acid soils. The aluminum concentration in the soil solution is high when the soil has a low pH.

As the pH increases with the development of reduced conditions when the soil is submerged, the aluminum concentration in the soil solution decreases and generally falls below the critical level for aluminum toxicity. Under such conditions, the iron level in the soil solution is raised and iron toxicity is very likely. For this reason, aluminum toxicity is rare in ordinary lowland rice but can occur under some conditions if reduction after flooding is slow.

MANGANESE TOXICITY

On certain soils, the manganese content in the plant may reach 3,000 ppm, an amount sufficient to indicate toxicity, but the plant does not show any visible symptoms. Such plants usually yield well. It is clear that total manganese content is not the only influence on the appearance of toxicity symptoms.

Since upland crops suffer from manganese toxicity, and since the manganese concentration of the soil solution increases after flooding, it is logical to expect toxicity in lowland rice. Rice, however, is more resistant to manganese toxicity than many other crops and the critical content is much higher. For instance, alfalfa may be affected by as little as 200 ppm Mn in tissues (*82*), barley by about 1,000 ppm Mn (*135*), while rice is affected only by about 2,500 ppm Mn (Table 1). A high level of iron in the growth media may counteract an excess uptake of manganese. Ammonia, which is the major nitrogen form in flooded soils, also has a retarding effect on manganese uptake in comparison with nitrate nitrogen which is the major form in upland soils (*119*).

Probably for these reasons, manganese toxicity is less common than expected. In many cases a high manganese content of rice plants is associated with high yield, possibly indicating that a high manganese content in the soil is associated with various favorable soil conditions.

SULFIDE TOXICITY

When a soil is submerged, concentrations of sulfide, bicarbonate, or organic acids in the soil solution increase. If submergence is continued in the presence of considerable sulfate, sulfide concentration in the soil solution may increase to a detectable level.

Sulfide is reported to inhibit the respiration and the oxidative power of the roots, thus retarding the uptake of various elements (*8*, *15*, *60*, *61*, *71*). Sulfide sometimes enters the plant and disturbs metabolic processes, even in the shoot (*108, 109*).

The major cause of "Akiochi" is considered to be hydrogen sulfide toxicity (*9, 56, 57, 98, 99, 112, 113*). If a soil is low in active iron and sulfide is produced in it, the sulfide stays in the soil solution without being precipitated as ferrous sulfide. The sulfide in the soil solution injures the roots, causes imbalanced and retarded uptake of nutrient elements, and eventually causes disturbed growth (*9, 56, 57, 97, 99, 100*).

Rice roots have an oxidizing power (*1, 20, 52, 55, 73, 96*) which causes the sulfide to be oxidized and lose its toxic effect (*11, 72, 110, 139*). When rice is healthy, the oxidizing power of the roots is strong, but when nitrogen is deficient the power becomes weak and the plant becomes susceptible to sulfide (*72, 73*). The soils on which "Akiochi" occurs generally have a low cation exchange capacity (*9*) and a large proportion of the ammonium nitrogen applied as fertilizer stays in the soil solution. Since uptake of nitrogen by the plant is active at early stages of growth, the nitrogen in the soil is soon exhausted, and the resulting nitrogen deficiency at later growth stages renders the plant susceptible to sulfide toxicity.

Plants suffering from an imbalance of nutrient elements are more susceptible to *Helminthosporium* leaf spots, especially if the plants are low in nitrogen, potassium, silica or manganese at later growth stages (*7, 15, 30, 57, 58*).

Soils on which "Akiochi" and "bronzing" occur have some similarities; i.e., low level of active iron, low cation exchange capacity, low levels of bases, etc. Plants suffering from these two disorders also have similarities, i.e., low content of potassium, magnesium, calcium, manganese, silica, etc.

"Bronzing" is considered to be iron toxicity, and "Akiochi" is attributed to hydrogen sulfide toxicity. Rice roots counteract a high level of ferrous iron in the soil solution by their oxidizing power. Ferrous iron is oxidized at the root surface to ferric iron and precipitated as ferric hydroxide or carbonate, resulting in a decreased intake of iron by the plant. Sulfide destroys the oxidizing power of the root and makes the plant more susceptible to iron toxicity (*126*). Plants suffering from "Akiochi" often have a higher iron content than normal plants (*83, 103*). In "Akiochi" soil, "bronzing" symptoms may also develop in certain varieties if the iron in the soil solution rises to a high level (*83*).

It therefore appears that "Akiochi," "bronzing," and "Akagare Type I" are disorders occurring on soils with similar characters, and that the causes of the disorders are related.

ORGANIC ACIDS AND CARBON DIOXIDE

Organic acids, such as acetate and butyrate, accumulate in submerged soil, especially a soil that has a high level of readily decomposable organic matter (*63a, 63b, 76, 116, 134, 140*). These acids are said to be toxic to rice roots and to retard nutrient uptake (*63a, 63b, 117, 140*). Carbon dioxide accumulates under similar conditions (*115*) and is also considered to be toxic to the roots (*22, 95, 133*). The accumulation of these acids is regarded as one of the causes of nutritional disorders of lowland rice on soils high in readily decomposable organic matter.

However, we doubt that these acids frequently accumulate in concentrations high enough to injure the roots. They are more toxic to the roots in an undissociated form (*125*). That means that at low pH they cause injury, but above pH 6 (pH 6 is common in submerged soils), the probability of toxic concentrations is slight.

These acids, however, can dissolve various substances in the soil. The concentration of ferrous iron or calcium may be considerably increased by an accumulation of acids, and a high ionic strength or concentration of iron or calcium may cause disturbances in the plant.

The effect of carbon dioxide may be important in soils of high pH because a high concentration of bicarbonate is likely in the soil solution. Bicarbonate may not have any drastic effect on the plant, but it may retard the uptake or translocation of various minor elements as is found in zinc deficiency.

SALINITY

During the survey, salinity injury was observed on alkali soils in northern India, on calcareous soils in the southern part of West Pakistan, and on acid sandy soils in the Korat region of Thailand. In addition, acid sulfate soils are potentially saline soils.

Salinity is generally associated with alkalinity in inland areas where evaporation is greater than precipitation. But salinity is usually associated with acidity in coastal areas. The common problem of both is high salt concentrations in the soil solution.

The most effective treatment is to wash the salts away by means of an irrigation drainage system. This requires a large investment in the construction of irrigation-drainage canals.

West Pakistan has well-distributed irrigation canals, but the limited amount of good water from them makes farming difficult. Underground water generally has high electric conductance and is therefore not as suitable for irrigation as canal water. Water electric conductance of more than 2,250 micro-mhos should not be used (*92*). Rice is most tolerant to salinity at germination, but is very sensitive at the subsequent seedling stage. It is also very sensitive at flowering and transplanting (*38, 84*). Therefore good water must be used at these stages. At other times rice is relatively tolerant to salinity and underground water of reasonably high electric conductance may be used for irrigation. If canal and ground water can be used in this way, salt injury can be partly alleviated.

Under weakly saline conditions, and if sodium is the major cation and potassium is deficient, the sodium may benefit rice growth by partially replacing potassium. It appears that when potassium supply is high, sodium is antagonistic to potassium absorption, but when potassium supply is low, the beneficial effects of sodium by partial replacement of potassium is more pronounced than the antagonism between the two elements. As a result, the presence of moderately high concentrations of sodium chloride can promote rice growth (*145*).

Varieties differ in resistance to salinity. In India, Jhona 349, Pokhali, and SR 26-B are known as salt-resistant varieties. IR8, a high-yielding variety named by The International Rice Research Institute, also is salt resistant (*38*). Salt resistance of a rice variety is one of the important factors determining its adaptability to a wide range of environments.

Conclusion

Nutritional disorders of the rice plant occurring in Asian countries can be classified as shown in Table 38.

Under flooded conditions soil undergoes reduction, and the concentration of iron may increase to a level high enough to induce iron toxicity. The level of iron in the soil solution is largely determined by the soil pH and the content of readily decomposable organic matter. Low pH and high organic matter content are associated with high iron concentration in the soil solution.

If a soil is high in active iron, especially when it is also high in easily reducible manganese, the soil is resistant to a lowering of the redox potential and the iron level in the soil remains low. Such soils have a high phosphorus absorption coefficient especially when they are high in active aluminum; phosphorus deficiency therefore tends to develop. If such soils contain a large amount of organic matter, iron content in the soil solution can be very high and the rice plant suffers from both phosphorus deficiency and iron toxicity. These disorders occur on soils formed from the early stages of laterization of basic rocks.

If a soil contains a large amount of easily reducible manganese, manganese toxicity may develop. However, such cases are probably not common.

If the active iron content is not high, the redox potential of the soil falls quickly, the iron concentration in the soil solution rises sharply, and iron toxicity may develop. Since there is a physiological interaction between iron and potassium, a low potassium status of the soil tends to aggravate iron toxicity.

Under reductive conditions, sulfate is reduced to sulfide. If there is little active iron to react with the sulfide, free sulfide may exist in the soil solution, damaging the roots and retarding nutrient uptake. As a result, the plant becomes unbalanced in nutrient content and susceptible to *Helminthosporium* infestation.

Low nitrogen status makes the roots more susceptible to hydrogen sulfide injury and the plants more susceptible to *Helminthosporium*. Potassium-deficient plants are also susceptible to *Helminthosporium*. Low cation exchange capacity of the soil is a causative factor in nitrogen or potassium deficiency at later stages of growth if nitrogen or potassium fertilizers are applied only as a basal dressing. Such soils also often have a low active iron content and are called "degraded paddy soils."

"Bronzing," "Akagare Type I," and "Akiochi" are related. All these disorders occur on sandy or silty soils low in cation exchange capacity and active iron. Small differences in the soil, such as pH, organic matter, potassium content, degree of drainage resulting from physiographic changes, and varietal characters may determine the type of disorder that appears.

Calcareous soils have a pH above 7 and the availability of elements such as phosphorus, iron, and zinc is low, leading to the corresponding deficiencies. Potassium deficiency may also occur if the soil is low in this element.

Soils high in sodium generally have a high pH and total soluble salts. Plants on these soils frequently suffer from a salinity problem and sometimes from iron deficiency and boron toxicity.

In neutral soils, availability of nutrients is just adequate and deficiencies or excesses of nutrients are unlikely. However, if a soil is low in an essential nutrient, plants may suffer from a deficiency of this nutrient.

Figure 11 is a summary of our observations of nutritional disorders of rice in Asian countries. Information collected from the literature is also included.

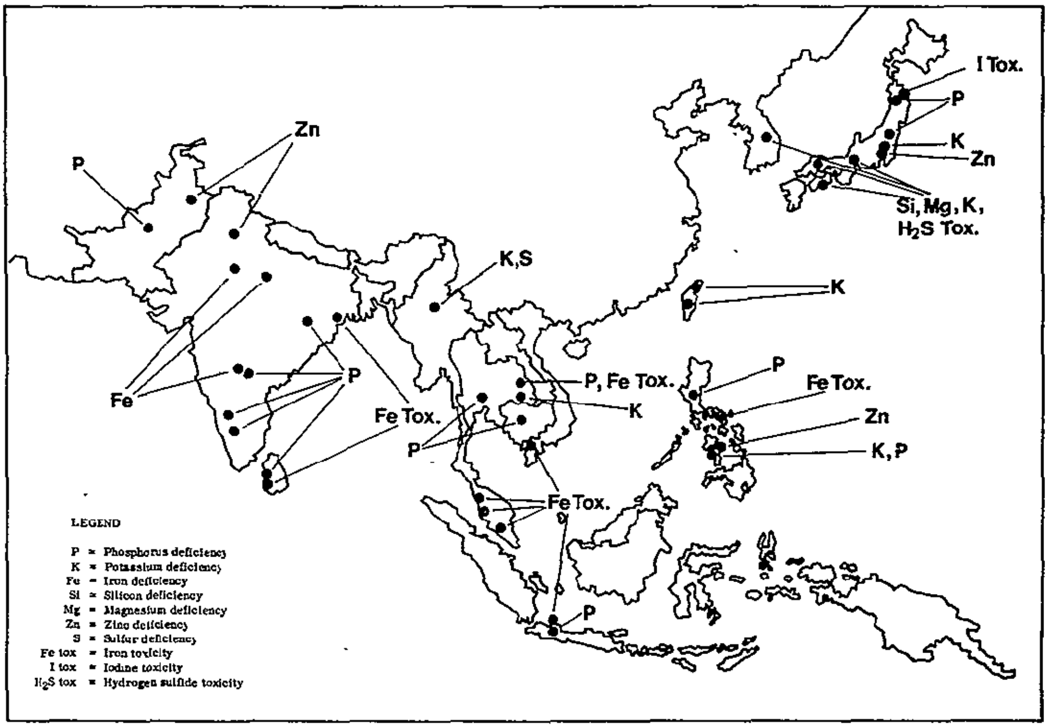

Fig. 11. Nutritional disorders of rice in Asia.

Table 38. Classification of nutritional disorders in Asia.

Soil		Soil condition	Disorder	Local name
Very low pH		(Acid sulfate soil)	Iron toxicity	"Bronzing"
Low pH	High in active iron	Low in organic matter	Phosphorus deficiency	
		High in organic matter	Phosphorus deficiency combined with iron toxicity	
		High in iodine	Iodine toxicity combined with phosphorus deficiency	"Akagare Type III"
		High in manganese	Manganese toxicity*	
	Low in active iron and exchangeable cations	Low in potassium	Iron toxicity interacted with potassium deficiency	"Bronzing" "Akagare Type I"
		Low in bases and silica, with sulfate application	Imbalance of nutrients associated with hydrogen sulfide toxicity	"Akiochi"
High pH		High in calcium	Phosphorus deficiency Iron deficiency Zinc deficiency	"Khaira" "Hadda" "Taya-Taya" "Akagare Type II"
		High in calcium and low in potassium	Potassium deficiency associated with high calcium	
		High in sodium	Salinity problem Iron deficiency Boron toxicity*	

* Probably rare.

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Appendix

Common virus diseases of South and Southeast Asia—symptoms and occurrence

Yellow dwarf disease: The first symptom of yellow dwarf is the general yellowing of the leaves, especially the newly emerged and young ones. The color varies from greenish-yellow to whitish-yellow. As the disease progresses, the infected plants become severely stunted and tillering increases markedly. They produce no, or only a few, small panicles bearing mostly unfilled grains.

Plants infected during the later growth stages may not show the characteristic symptoms before harvest. However, the symptoms are conspicuous on the regenerated (ratoon) growth from cut stubbles. Ratoon growth showing a high incidence of yellow dwarf often occurs in the field.

Yellow dwarf is distributed over a wide rice-growing area, including Ceylon, India, Japan, Malaysia, Okinawa, the Philippines, South China, Taiwan, and Thailand.

Orange leaf disease: The diseased plants, which are usually scattered in the field, have golden yellow to deep-orange leaves when about a month old. Later, these discolored leaves gradually roll inward and dry out starting at the tips. Under greenhouse conditions, the first symptoms appear on the outer margin or on only one side of the leaf blade near the tip of the leaf. One or more well-defined orange stripes run parallel to the veins. Later, the leaves rapidly turn orange, then roll and become dry. Infected plants often die quickly. Diseased plants which do not become conspicuously stunted tend to develop fewer tillers, and their root development is poor. When plants are infected at a later stage, panicles may develop but may not be completely exserted from the sheath; moreover, the grains are often unfilled.

The disease was first observed in northern Thailand in 1960. In 1963, it was also observed in the Philippines and identified as a virus disease. The disease has also been reported to occur in Ceylon.

Tungro disease: The infected rice plants, especially of very susceptible varieties, are stunted, the number of tillers is slightly reduced, and the leaves are yellow. The plant becomes stunted through a shortening of both the leaf sheath and the leaf blade. Because of the limited elongation of the new leaf sheath, the unfolded leaf is sometimes clasped by the outer leaf sheath. The degree of stunting varies among rice varieties and the reduction in plant height decreases with increasing plant age at the time of infection. Tillering is also influenced by the age of infected plants. The number of tillers is significantly reduced when plants are infected at the early growth stage. The number may increase if infection occurs when the plant is more than a month old, but remains the same if infection takes place during the late growth stage. Yellowing, which ranges from light yellow to orange-yellow or brownish yellow, usually starts from the tip of the leaves. The color varies among rice varieties and with environmental conditions. Irregularly shaped dark-brown blotches frequently develop on the yellow leaf and occasionally on the green leaf, especially in infected young seedlings. The young leaves of infected plants are often mottled with pale-green to whitish stripes of various lengths running parallel to the veins. Root development is poor. The infected plants take longer to mature because of delayed flowering. The panicles are often small, sterile, and are not completely exserted. The grains are often covered with dark-brown blotches and weigh less than those of healthy plants but the low yields are mainly due to the lower number of grains per plant. Yield reduction varies among varieties and decreases gradually with increasing plant age at the time of infection.

The symptoms of infected plants of some varieties may be completely masked after a certain growth period. Later, the plants may again show the symptoms, may develop symptoms only on the tillers, or may remain without symptoms.

Microscopic examination of sections after being stained with Giemsa solution revealed that there were stained, somewhat round inclusion bodies in some parenchyma cells of the vascular bundle of the diseased leaves. The size of the inclusion bodies seemed to vary with the size of cell.

The leaves of diseased plants often become dark after being treated with iodine solution. This contrasts strikingly with the absence of any color reaction by the healthy plants. The starch accumulation in the leaf blade could be due to the effect of the virus on the metabolism of carbohydrates. However, the starch reaction test might be applied for diagnosing the disease.

The tungro virus has two strains, "S" and "M." Although the symptoms produced by these strains are similar in rice varieties such as IR8, Milfor-6(2), Palawan, Taichung (Native) 1, and Tainan 3, they can be differentiated in such varieties as Acheh, FK-135, and Pacita. The symptom produced by the "S" strain on these three varieties is conspicuous interveinal chlorosis, giving an appearance of yellow stripes and sometimes irregular chlorotic specks on young leaves. The "M" strain produces mottling symptoms.

The disease has been known to occur in the Philippines for many years. It also occurs in Indonesia.

Transitory yellowing disease: The symptoms of transitory yellowing and tungro are similar. The characteristic symptoms of transitory yellowing consist of yellowing of leaves, reduced number of tillers if the plants are infected at the early growth stage, and stunting of the plants. The discoloration of the leaves usually starts from the distal portion of the lower leaves. Therefore, the color is more intense in the lower leaves than in the upper ones. Few to many brown rusty flecks or patches may appear on the discolored leaves. The infected plants have a poor root system as compared with the healthy ones. The early infected plants produce no panicles or very poor ones.

The diseased plants often show some degree of recovery under greenhouse conditions. Following an acute stage of leaf yellowing for about a month or so, the infected plants may gradually recover and produce no yellow leaves at the later growth stage. Consequently, the appearance of the diseased plants may become normal after the leaves which had previously shown yellowing fall away. This explains the name, transitory yellowing. The indica varieties have relatively good ability to recover from disease.

Large, round inclusion bodies are present mostly in parenchyma cells around the vascular bundles and also in the smaller parenchyma cells surrounding the xylem vessels and sieve tubes in the leaf and root of diseased plants. These bodies are cylindrical and vary in length and thickness in longitudinal sections. They consist of homologous protoplasm without vacuoles, implying that the nucleus is contained within them.

Based on both the iodine test and chemical analysis, the results indicated that the starch accumulated in the leaf blades of diseased plants, which is not the case with the "suffocating" disease. Therefore, dipping the basal portion of the leaf blades in 0.6 percent iodine solution immediately after sampling has been suggested as a technique for field diagnosis in order to distinguish transitory yellowing from the "suffocating" disease. The disease occurs in southern Taiwan.

Grassy stunt disease: When fully developed, the diseased plants are characterized by severe stunting, excessive tillering, and erect habit. The leaves are short, narrow, and pale green or pale yellow, and often have numerous small dark-brown dots or spots of various shapes or forming blotches. Sometimes, mottling or striping may appear on young leaves of some varieties. The infected plants usually live until maturity but they produce at best a few small panicles which bear dark-brown and unfilled grains.

The disease has been observed in various parts of the Philippines, Ceylon, India, and other countries. The rice rosette disease in the Philippines appears similar to grassy stunt in symptomology, vector species, and virus-vector interaction.

Adapted (by permission of the author) from "Virus diseases of the rice plant" by K.C. Ling, The International Rice Research Institute, 1968.

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Nutritional disorders of rice in Asia

1. Deficiencies of nitrogen, phosphorus, and potassium (water culture)

2. Phosphorus deficiency (water culture)

3. Potassium deficiency in absence of NaCl (water culture)

4. Magnesium deficiency (water culture)

5. Manganese deficiency (water culture)

6. Growth at different levels of nitrogen (water culture)

7. Sulfur deficiency (water culture)

8. Calcium deficiency (water culture)

9. Zinc deficiency (field, Pant Nagar, India)

10. Zinc deficiency (soil pot culture with added cellulose)

11 Zinc deficiency (field, Cebu, Philippines)

← 12. Zinc deficiency (field, Kala Shah Kaku, West Pakistan)

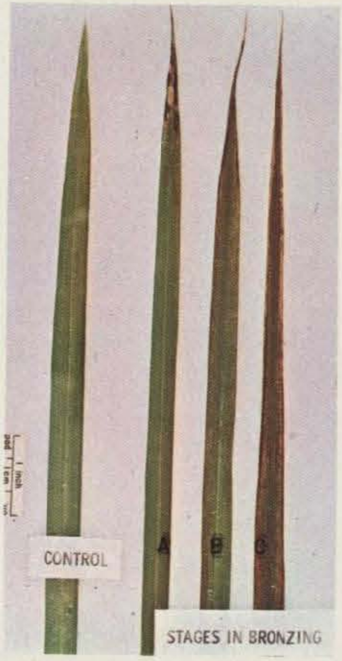
↑ 13. Low silicon (water culture)

14. Iron deficiency (upland field, Rajendranagar, India)

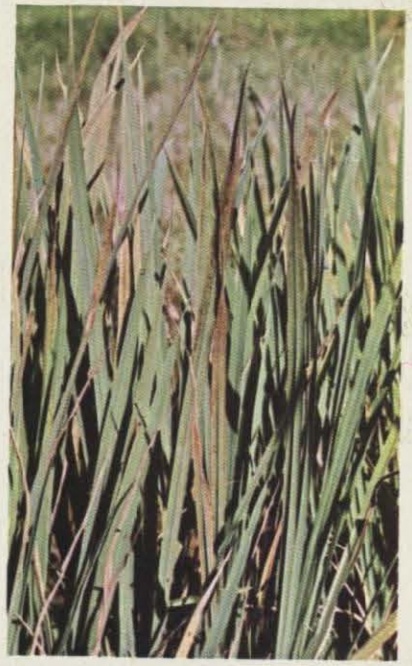
15. Boron deficiency (water culture)

16. Iron deficiency (field, Indian Agricultural Research Institute, India)


17. Iron toxicity (field, Bombuwela, Ceylon)



18. Iron toxicity (water culture)


19. Iron toxicity — Brown type (field, Bombuwela, Ceylon)


20. Iron toxicity — Yellow type (field, Bombuwela, Ceylon)


↑ 21. Manganese toxicity (water culture)


→ 22. Manganese toxicity (water culture)


23. Aluminum toxicity (water culture)


24. Boron toxicity (water culture)

25. Salinity injury (field, Vanarasi, India)

26. Salinity injury (water culture)

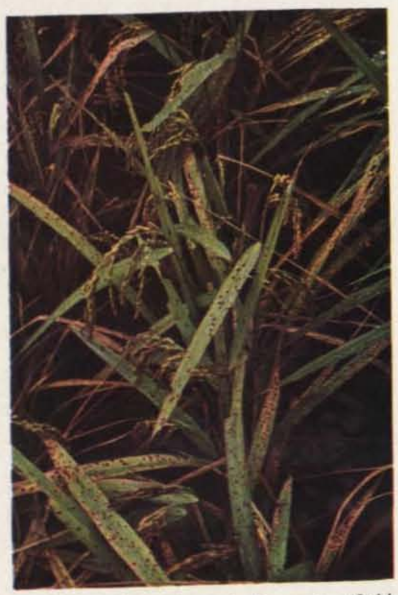
27. Akagare — Potassium deficiency (field, Nongso, Korea)

28. Akagare Type I (same field as plate 27)

29. Akagare Type II — Zinc deficiency (field, Chiba, Japan)

30. Akagare Type III — Iodine toxicity (field, Iwate, Japan)

31. Disorder — formerly called suffocating disease (field, Ilang, Taiwan)



32. Helminthosporium leaf spots (field, Suwon, Korea)