BORON DEFICIENCY OF CROPS IN TAIWAN

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ABSTRACT

Boron is a an important micronutrient for crops, but its role in plant nutrition is still the least understood of all mineral nutrients. Boron deficiency is a widespread nutritional disorder. This Bulletin discusses factors affecting boron availability in soils, including the parent material, the pH, soil texture and clay minerals, soil moisture, temperature, organic matter, nutrient interaction and plant species. Environmental conditions and the published data show that soils in Taiwan are low in available boron. Crops grown on these soils are liable to suffer from boron deficiency. The Bulletin describes the diagnosis and correction of boron deficiency for several crops, including sugar beet, papaya, citrus, and pineapple, over a range of soil types. Significant errors may occur when using the traditional hot-water-soluble extraction method is used to assess the available boron in soil. An improved method, using a boron-specific ion exchange resin Amberlite IRA-743 to assess available boron in soils, is recommended. It is simple to apply, and the results are less variable.

INTRODUCTION

Boron is an important micronutrient for vascular plants, diatoms and some species of marine algal flagellates, although it is apparently not required by bacteria, fungi, green algae or animals (Loomis and Durst 1992). Some species of cyanobacteria require boron for nitrogen fixation. That boron is essential for the growth and development of higher plants was first demonstrated in 1923 by Warington. Since that time, our knowledge of the importance of boron in agriculture has grown rapidly.

Of all known plant micronutrient deficiencies, that of boron is most widespread (Gupta 1993). A deficiency of boron, shown by a positive response to boron application, has been reported in more than 80 countries and for 132 crops over the last 60 years (Shorrocks 1997). In Taiwan, boron deficiency was first reported in some vegetable crops, including tomato, cauliflower, radish, lettuce and celery (Yuh 1956). In the 1960s, sugar beet and fodder beet were introduced by the Taiwan Sugar Experiment Station into experimental fields. At that time, widespread boron deficiency was noted (Chyi and Deng 1956, cited by Yang 1960a). Since then, boron deficiency has become recognized as an important problem in Taiwan. However, there is relatively little research into boron in Taiwan, compared to macronutrients. This situation may be partly because of the difficulty of determining boron levels. This problem has recently been solved by the development of the spectrophotometric method, using the water-soluble complexing agent azomethine-H. Even more recently, new spectrometric techniques using a plasma source offer a simple and reliable method of analyzing levels of boron in crops and soils. They are likely to awake a new interest in this element.

This Bulletin reviews the role of boron in plant nutrition, and the factors affecting boron availability in soils. This is followed by a number of case studies of the diagnosis and correction of boron deficiency in crops and soils in Taiwan. Finally, there is a discussion of the various methods in current use for measuring the amount of available boron in the soil.

Keywords: availability, boron requirements, boron, boron uptake, deficiency symptoms, parent material, soil pH, soil type, Taiwan

THE ROLE OF BORON IN PLANT NUTRITION

Boron is absorbed from the soil solution by roots mainly as undissociated boric acid. Its uptake in higher plants is closely related to the pH and boron concentration in the soil solution, and is probably a passive process. Its distribution in plants is primarily governed by the transpiration stream through the xylem (Raven 1980), although it is also phloem mobile, and considerable amounts might be retranslocated (Shelp 1993, Brown and Shelp 1997).

Boron is the least understood of all the mineral nutrients, in terms of its role in plant nutrition. Loomis and Durst (1992) have published a detailed review of the probable role of boron in higher plants. Almost all hypotheses are based on observed abnormalities in plants when boron was withheld from the culture media. Whether these abnormalities reflect a primary function of boron, or whether they are only a secondary consequence of the primary effect, can be assessed only by noting the timing of any changes in metabolic activity and/or morphology. Therefore, it is very important to detect the earliest signs of boron deficiency. Hirsch and Torrey (1980) listed a timetable of early symptoms of boron deficiency. However, it is not possible to judge with confidence which event is the earliest, because the physiological changes are not always visible, and are often quite subtle. Also, it is likely that the time lag before deficiency symptoms begin to show depends on the degree of stringency of boron removal. This also makes it difficult to differentiate primary functions and secondary functions of boron.

Boron is not a constituent of enzymes in plant, nor is there evidence that it directly affects enzyme activities. There is a long list of possible roles of boron (Parr and Loughman 1983), including sugar transport, cell wall synthesis, lignification, cell wall structure integrity, carbohydrate metabolism, RNA metabolism, respiration, indole acetic acid (IAA) metabolism, phenol metabolism, and as part of the cell membranes. This long list might indicate, either that boron is involved in a number of metabolic pathways, or that there is a “cascade effect”, as is known of the phytohormones, for example.

There is increasing evidence for the latter alternative, and that boron plays a primary role in biosynthesis and structure of cell walls, and in the integrity of plasma membrane. Overall, the published data indicate that in higher plants, boron exerts its primary influence in the cell wall and at the plasma membrane-cell wall interface. Changes in the cell wall and at this interface are considered to be a primary effect of B deficiency, which leads in turn to a cascade of secondary effects in metabolism, growth and plant composition.

Boric acid has a strong ability to form complexes with diols and polyols, particularly with cis-diols (Loomis and Durst 1992). The high boron requirement of gum-producing plants is probably related to the function of boron in forming cross-links with the various polyhydroxy polymers (Loomis and Durst 1991).

In higher plants, at least, a substantial proportion of the total boron content is complexed in cis-diol configuration in the cell walls (Thellier *et al.* 1979). The higher boron requirements of dicotyledonous species, compared to graminaceous species, is presumably related to the higher proportions of compounds with the cis-diol configuration in the cell walls, such as pectic substances (Loomis and Durst 1992). It has been shown by Tanaka (1967) that the content of strongly complexed boron in the root cell walls is 3-5 µg g^{-1} dry weight in graminaceous species such as wheat, and up to 30 µg g^{-1} dry weight in dicotyledonous species such as sunflower. These differences roughly reflect the differences between these two crops in boron requirements for optimal growth.

FACTORS AFFECTING BORON AVAILABILITY IN SOILS

There are a number of soil and environmental factors that affect boron uptake by plants. Knowing these will improve our assessment of boron deficiency and toxicity under different conditions.

When boron is released from soil minerals, or is mineralized from organic matter, or is added to soils by means of irrigation or fertilization, part of it remains in the soil solution while part of it is adsorbed by the particles of soil. Minerals which contain boron are either very insoluble (tourmaline) or very soluble (hydrated boron minerals). They do not usually determine the solubility of boron in the soil solution (Goldberg 1993), which is controlled mainly by boron adsorption reactions. An equilibrium exists between the soil solution and adsorbed boron (Russell 1973).

Since plants obtain boron from the soil solution (Hatcher *et al.* 1959), and the adsorbed pool of B acts as a buffer against sudden changes in the level of boron in the soil solution (Hatcher *et al.* 1962), it is important to know how boron is distributed

Table 1. Levels of boron in common rock types

Class of rock	Type of rock	Concentration, mg/kg
Igneous	Granite	15
	Basalt	5
Metamorphic	Limestone	20
Sedimentary	Standstone	35
	Shale	100
Level of boron found in derived soils		2-100

Source: Krauskopf 1972

between the solid and the liquid phases of the soil. Factors affecting the amount of boron adsorbed by soils, and the availability of boron in soils, include pH, soil texture, soil moisture, temperature and management practices such as liming and so on. (Evans and Sparks 1983).

Parent Material

The level of boron in common rocks is shown in Table 1 (Krauskopf 1972). In general, soils derived from igneous rocks, and those in tropical and temperate regions of the world, have a much lower boron content than soils derived from sedimentary rocks, and those in arid or semi-arid regions. Soils of marine shale origin are usually high in boron. A low boron content can be expected in soils derived from acid granite and other igneous rocks, fresh-water sedimentary deposits, and in coarse-textured soils low in organic matter (Liu *et al.* 1983). Plant availability of boron is also reduced in soils derived from volcanic ash (Sillanpaa and Vlek 1985) and in soils rich in aluminum oxides (Bingham *et al.* 1971).

pH

Soil reaction is one of the most important factors affecting the availability of boron in soils. When the soil solution has a high pH, the boron it contains becomes less available to plants. Therefore, applying lime to acid soils can sometimes result in boron deficiency symptoms in plants. The level of soluble boron in soils has a close correlation with the pH of the soil solution (Berger and Truog 1945, Elrashidi and O'Connor 1982). The boron uptake by plants growing in soil with the same water soluble boron content was greater when the pH of the soil solution was lower (Wear and Patterson 1962).

The adsorption of boron by soils depends very much on the pH of the soil solution. Boron adsorption by soils increased when the pH rose to the range 3 - 9 (Barrow 1989, Bingham *et al.* 1971, Keren and Bingham 1985, Mezuman and Keren 1981). It decreased again when the pH was even higher, in the range 10 - 11.5 (Goldberg and Glaubig 1986). The highest levels of boron absorption by soil had a close correlation with the pH of the soil solution (Evans 1987, Okazaki and Chao 1968).

Soil Texture and Clay Minerals

Coarse-textured soils often contain less available boron than fine-textured soils. For this reason, boron deficiency often occurs in plants growing in sandy soil (Fleming 1980, Gupta 1968). The level of native boron is closely related to the clay content of the soil (Elrashidi and O'Connor 1982). At the same water soluble boron content, boron uptake was highest in plants growing in the soil with the coarsest texture (Wear and Patterson 1962). The level of boron adsorbed by the soil thus depends on soil texture. It increases as the clay content increases (Bhatnager *et al.* 1979, Elrashidi and O'Connor 1982, Mezuman and Keren 1981, Wild and Mazaheri 1979).

Of the clay types commonly found in soil, illite adsorbed more boron than either kaolinite or montmorillonite. Kaolinite absorbed the least (Fleet 1965, Hingston 1964). Frederickson and Reynolds (1959) proposed that most of the boron in the clay mineral fraction of sedimentary rocks is contained in the illite fraction. Sims and Bingham (1976, 1968a,b) found that B adsorption was greater for Fe- and Al-coated kaolinite or montmorillonite than for uncoated clays. They concluded that hydroxy Fe and Al compounds present in the layer as silicates or as impurities dominate over clay mineral species *per se* in determining B adsorption characteristics. Bingham *et al.* (1971) and Schalscha *et al.* (1973) also concluded that boron adsorption by certain soils was primarily due to their aluminum oxide content.

Soil Moisture

Boron availability generally decreases as soils become dry, so that boron deficiency is more likely in plants suffering from a water deficit (Fleming 1980). This may be because plants encounter less available boron when they extract moisture from soil at a lower depth during dry conditions (Fleming 1980). Wetting and drying cycles increased the amount of boron fixation (Biggar and Fireman 1960). The effect of drying became more pronounced as more boron was added (Biggar and Fireman 1960).

Temperature

Boron adsorption rises with higher soil temperatures. However, this may reflect the interaction between soil temperature and soil moisture, since boron deficiency is often associated with dry summer conditions (Fleming 1980).

Organic Matter

Many researchers have suggested that the level of soil organic matter influences the availability of boron to plants. However, there is little information about the role of organic matter in boron nutrition. The strongest evidence that organic matter affects the availability of soil boron is derived from studies that show a positive correlation between levels of soil organic matter and the amount of hot-water-soluble boron (Gupta 1968, Kao and Juang 1978, Chang *et al.* 1983).

The association between boron and soil organic matter is said to be caused by the assimilation of boron by soil microbes (Gupta *et al.* 1985). Although the boron present in soil organic matter is not immediately available to plants, it seems to be a major source of available boron when it is released through mineralization (Gupta *et al.* 1985).

The need to apply boron to peat soils is widely recognized (Prasad and Byrne 1975). The results indicate that the reduction in boron uptake at a high pH referred to above is partially due to the chemical reaction between limed peat and applied boron. Crops grown on peat do not generally show any symptoms of boron toxicity when boron is applied at rates that would usually produce toxicity on mineral soils (Gupta 1979). No boron toxicity was reported in sweet corn grown on a peat soil, even when the concentration of hot-water-soluble boron was as high as 10 mg kg^{-1} (Prasad and Byrne 1975).

Nutrient Interactions

The ratio between calcium and boron in the plant is sometimes used to identify boron deficiency. However, Gupta (1978) concluded that this ratio should not be given the same importance as levels of each separate element. Gupta and MacLeod (1977) found that if no extra boron is applied, a lower boron uptake seems to be related to a higher soil pH, rather than to the availability of calcium or magnesium. If boron was applied, this effect was not seen.

Applied boron may improve the utilization of applied nitrogen by cotton plants by increasing the translocation of N compounds into the boll (Miley *et al.* 1969). Smithson and Heathcote (1976) found that when boron deficiency occurred in cotton, the application of 250 kg N/ha reduced the yield. However, if boron was applied, the same application of N increased the yield.

A significant relationship has been found between potassium and boron fertilizers (Hill and Morrill 1975). Woodruff *et al.* (1987) showed that boron may need to be applied to prevent a reduction in corn yield, if the crop is given heavy applications of potassium and other intensive production practices.

Change *et al.* (1994) studied the correlation between available nutrients in the top 75 cm of soil and the nutrient concen-tration in citrus leaves. There was no significant correlation between the levels of phosphorus and potassium. However, there was a significant correlation in the levels of calcium, magnesium and boron. If the level of calcium in the soil (measured by Mehlich's method) is above 500 ppm, the magnesium is more than 100 ppm, and the hot-water-soluble boron content more than 0.20 ppm, then the leaves are likely to contain more than 2.5% Ca, 0.25% Mg, and 25 ppm boron. This is the criteria to diagnose adequate levels of these elements for citrus in Taiwan.

Graham *et al.* (1987) found that boron uptake by barley was lower if zinc was applied than if it was not. Further studies showed that low levels of zinc and high levels of phosphorus both increased the rate of boron accumulation. Therefore, applying zinc may reduce boron accumulation, and lessen the risk of toxicity in plants.

Plant Factors

Plant species differ in their capacity to take up boron, even when they are grown in the same soil. These differences generally reflect different boron requirements for growth. For example, the critical deficiency ranges, expressed as mg boron per kilogram dry weight, is about 5-10 mg in graminaceous species such as wheat. However, in most dicotyledonous species such as clover it is 20 - 70 mg, and in gum-bearing plants such as poppy it is 80 - 100 mg (Bergmann 1988, 1992).

These differences in the boron demand of graminaceous and dicotyledonous species is probably related to the differences in their cell wall composition. In graminaceous species, the cell walls contain very little pectic material. Such species also have a much lower calcium requirement. Interestingly, these two plant groups also differ in their capacity for silicon uptake, which is usually inversely related to boron and calcium requirements (Loomis and Durst 1992). All three elements are located mainly in the cell walls. Reports on calcium/boron interactions are so far inconclusive (Gupta 1979, Bergmann 1988, 1992). However, these interactions are likely to have a physiological basis. Both elements are likely to have similar structural functions in the cell walls and at the cell wall-plasma membrane interface and similar interactions in uptake and shoot transport and in IAA transport. These common features also explain certain similarities in symptoms of calcium and boron deficiency, for example in peanut seeds (Cox and Reid 1964) and lettuce (Crisp *et al.* 1976).

In general, boron deficiency is most common under the following soil conditions.

- In soils which are inherently low in boron, such as those derived from acid granite and other igneous rocks, and freshwater sedimentary deposits;
- In naturally acid soils, from which much of the native boron content has been removed by leaching;
- In light-textured sandy soils and gravelly soils;
- In alkaline soils, especially those which are calcareous;
- In irrigated soils where the boron content in irrigation water is low, and where salt or carbonate has been deposited;
- In soils low in organic matter; *and*
- In soils which suffer from drought when the rainy season has ended.

BORON STATUS OF AGRICULTURAL SOILS IN TAIWAN

Lying in both tropical and subtropical zones, Taiwan is warm and has plenty of rainfall. Soils in Taiwan are thus subject to leaching. They are moderately to highly weathered, especially those located in the northeast and in mountainous areas.

Most of the agricultural soils in Taiwan (more than 80% of the farming area) are medium- to coarse-textured throughout the whole soil profile (Table 2). One-third of the agricultural surface soils in Taiwan are strongly acidic, especially in slopeland areas and in the northern part of Taiwan. About two-thirds of the agricultural soils of Taiwan have an organic matter content of less than 2%.

From these conditions, we could conclude that boron deficiency is rather common in the agricultural soils of Taiwan. The content of hot-water-soluble boron (HWS-B) in typical Taiwan agricultural soils is listed in Table 3 (Yang 1960). In general, the boron content is higher in surface soil than in subsoil, and lower in acid soils than in basic or neutral soils. Soils along the sea shore, as well as those derived from mudstone, are generally rich in boron. Lateritic soils, and soils derived from sandstone, slate or crystalline limestone, do not contain much boron.

Soils in Taiwan have been categorized by Yang (1960) into three groups, based on their level of hot-water-soluble boron. The critical level for sugar beet was 0.1 ppm. Sugar beet will certainly show symptoms of boron deficiency on soils with less than 0.1 ppm B. At 0.1-0.2 ppp B, sugar beet may sometimes have deficiency symptoms. If soils have more than 0.2 ppm B, sugar beet will probably have enough boron to meet the physiological needs of the plant.

Kao and Juang (1978) listed the content of hot-water-soluble boron in representative soils from sugarcane growing areas. They showed that calcareous sand and shale alluvial soils have a high boron content, ranging from 0.63 to 1.12 ppm (an average of 0.9 ppm). The boron content of mixed alluvial soils was 0.5 ppm on average. Lateritic soils, non-calcareous sandstone, shale and slate alluvial soils all had a low boron content (i.e. 0.3 ppm, 0.24 ppm, and 0.19 ppm on average, respectively). Black soils had a surprisingly high boron content of 0.9 ppm. Based on the growth response of young sugarcane to applied boron, Kao

Table 2. The distribution of soil texture in Taiwan agricultural soils

Soil texture class	Distribution(%)			
	0-30 cm depth	30-60 cm depth	60-90 cm depth	90-150 cm depth
Gravel	0	18.2	21.2	25.1
Coarse (S, LS)	3.1	5.7	7.0	7.0
Moderately coarse (SL)	25.5	15.0	19.4	19.4
Medium (L, SiL, Si)	55.0	36.1	28.0	23.1
Moderately fine (SCL, SiCL, CL)	15,9	14.7	14.7	14.0
Fine (SC, SiC, C)	0.5	10.2	9.7	11.3

and Juang (1978) concluded that the critical level of boron in the soil was 0.44 ppm. This is much higher than the level proposed by Yang (1960).

The level of hot-water-soluble boron in the soils from sugarcane-growing areas showed a positive correlation with soil reaction and organic matter content, reaching a significant level of 5% and 1%, respectively.

Lee and Lin (1975) investigated the micronutrient content of soils in the main vegetable-growing areas of Taiwan. They concluded that the hot-water-soluble boron (HWS-B) content of these soils ranged from 0.1 to 1.75 ppm, but that four-fifths had a boron content lower than 0.5 ppm. Although most of these soils thus have a low boron content, there were no symptoms of boron deficiency or toxicity in vegetable crops. Nor did the application of boron affect vegetable yields.

Chang *et al.* (1983) studied the soil boron status of papaya-growing areas in eastern Taiwan. They found that the level of HWS-B was affected by the type of parent material, the organic matter content, the duration of leaching and the irrigation water. The HWS-B content of papaya orchards ranged from 0.01 to 0.84 ppm.

Soils classified as latosols had the lowest HWS-B content (mean value: 0.07 ppm). Old slate alluvial soils came next (0.15 ppm), then recent slate alluvial soils (0.21 ppm). Black soil had the highest level of HWS-B (0.28 ppm). Old slate alluvial soils in upland areas, where fields were rainfed and had shallow soils, had a lower HWS-B content (0.09 ppm) than paddy fields with deep soil and poor drainage (0.39 ppm). The higher level of HWS-B in paddy fields was probably introduced in irrigation water. Boron deficiency was common in papaya growing in latosols or old slate alluvial soils in upland areas.

Slopeland soils of eastern Taiwan derived from slate and schist had a lower HWS-B content than those derived from mudstone or igneous rock. Just as the organic matter content is higher in surface soil than in the subsoil, so is the level of HWS-B. There was a significant relationship between levels of organic matter and HWS-B in soils derived from slate and schist. This relationship was not found in soils derived from mudstone and igneous rock.

Reisenauer *et al.* (1973) roughly categorized soils into three groups, on the basis of how much HWS-B they contained.

- Less than 1.0 ppm boron - the soil may not supply sufficient boron to support normal plant growth.
- 1.0 - 5.0 ppm boron - the soil generally supplies enough boron to allow normal plant growth.
- Greater than 5.0 ppm boron - the soil may supply toxic concentrations of boron.

According to these categories, most of the agricultural soils in Taiwan are rather low in boron, and may not supply enough for normal crop growth.

DIAGNOSIS AND CORRECTION OF BORON DEFICIENCY IN CROPS AND SOILS OF TAIWAN

Sugar Beet

Occurrence of Boron Deficiency

As stated above, lateritic soils, and soils derived from sandstone, slate or crystalline limestone contain low levels of HWS-B. Sugar beet growing in such soils always suffer from boron deficiency (Yang 1960a, 1960b).

Sugar beet grown in soils neutralized with lime are more likely to suffer from boron deficiency than those growing in acid soils. Sugar beet irrigated with rainwater are more likely to suffer from boron

Table 3. The content of water-soluble boron in different soils in Taiwan*

Soil group	Total no. of samples	<0.1 ppm NO. of samples	<0.1 ppm %	0.1 - 0.2 ppm No. of samples	0.1 - 0.2 ppm %	> 0.2 ppm NO. of samples	> 0.2 ppm %
Crystalline limestone and schist alluvial soils	13	8	62	5	39	0	0
Lateritic soils	26	14	54	12	46	0	0
Slate alluvial soils	105	45	43	51	49	9	9
Sandstone-shale alluvial soils	22	8	36	14	54	0	0
Sandstone-mudstone alluvial soils	27	6	22	19	70	2	7
Coastal alluvial soils	45	2	5	6	13	37	82
Mudstone alluvial soils	29	1	3	2	7	26	90

*Re-tabulated data from Yang 1960a

deficiency than those irrigated with groundwater. Dry soils favor the appearance of boron deficiency symptoms.

Basic fertilizers such as lime or calcium cyanamide, and a lack of organic fertilizers, are all unfavorable to boron nutrition of sugar beet. Boron deficiency symptoms in sugar beet always occur during vigorous growth periods.

Diagnosis of Boron Deficiency

As stated above, sugar-beet plants show symptoms of boron deficiency if the level of HWS-B in the soil is less than 0.1 ppm. Early symptoms of boron deficiency in sugar beet are white, netted chapping of the upper surface of the leaves, and wilting of the tops. This wilting may occur even in plants growing in moist soil or a hydroponic system. Young leaves wilt before older leaves, whereas with a true water shortage, the young leaves wilt last. In time, the young leaves collapse and fail to develop.

Other symptoms are pronounced crinkling of leaf blades, and darkening and cracking of the petioles. Eventually, the growing point dies, and the crown darkens and becomes subject to rot or decay. Internal and external crown darkening are symptoms which are easily identified in the field (Bennett 1993).

The leaves of beet with boron deficiency contain about 20 ppm B. This can be compared to the level of 40 - 65 ppm B found in normal sugar-beet plants.

Correction of Boron Deficiency

In pot experiments, the application of 0.06 g of borax to 40 kg soil deficient in boron was sufficient to solve the problem. In field experiments, 10 - 30 kg/ha of applied borax was enough to prevent boron deficiency.

Papaya

Occurrence of Boron Deficiency

Boron deficiency of papaya is common in latosols and old slate alluvial soils in upland areas of Taiwan. (Wang *et al.* 1975, Chang *et al.* 1983, Chang 1993). Boron deficiency becomes more likely if papaya trees are planted in sandy soils during the dry season.

Diagnosis of Boron Deficiency

The critical level of HWS-B for papaya was found to be 0.28 ppm for soils classified as black soil (derived from igneous rock and rich in organic matter) and 0.15 ppm for other soil groups. This difference may be because of the higher organic matter content of black soil.

One of the earliest signs of boron deficiency is a mild chlorosis in mature leaves, which become brittle and tend to curl downwards. A white "latex" exudate may flow from cracks in the upper part of the trunk, from leaf stalks, and from the underside of the main veins and petioles. The death of the growing point is followed by a regeneration of the sideshoots, which then ultimately die.

In fruiting plants, the earliest indication is flower shedding. When fruit develop, they are likely to secrete a white latex. Later, the fruit become deformed and lumpy. The deformation is probably the result of incomplete fertilization, as most of the seeds in the seed cavity are either abortive, poorly developed or absent. If symptoms begin when fruit are very small, most of the fruit do not grow to their full size.

Papaya fruits with a rugged surface and secreting latex are typical symptoms of boron deficiency. In studies of boron deficiency in papaya in Taiwan, samples were taken from the 10th leaf blade (without petiole), counted from the 1st leaf (the most recently matured leaf, with a leaf blade which has only just fully developed, and which has a brownish color on the petiole). Standard sampling of this kind can effectively reflect variations in the boron content in different orchards. The boron content of the 10th leaf blade of papaya trees with deformed fruit was always lower than 20 ppm, while that of leaves from normal trees was generally 25 - 155 ppm.

Correction of Boron Deficiency

Suggested rates of soil application for the correction of boron deficiency in papaya are 2.5 - 5 g of borax per plant, or 5 - 10 kg of borax per hectare. Foliar application of 0.5 g of borax per plant in a 0.25% solution per plant is effective.

Citrus

Occurrence of Boron Deficiency

Citrus is one of the most important fruits grown in Taiwan. Most citrus orchards are in slopeland areas, where soils are strongly acidic, with a low organic matter content. According to a survey of mandarin orchards in Taiwan in 1982 and 1983 (Chang *et al.* 1992, Lian *et al.* 1989), two-thirds of orchards have a surface soil with a pH value of less than 5.0, while half had a soil organic matter content lower than 2.0%. Since in the past, farmers used to fertilize their orchards without any soil testing, nutritional problems were common in orchards. The major nutritional problems for citrus in Taiwan are an excess of nitrogen, and low levels of potassium, magnesium, zinc and boron. Acidic slopeland soils are frequently low in available boron, and typical symptoms of boron deficiency and toxicity have been found in citrus orchards in Taiwan. Severe boron deficiency was reported by Chiu and Chang in a drought year (Chiu and Chang 1985, Chang *et al.* 1992, Chang 1993, Chang *et al.* 1994).

Diagnosis of Boron Deficiency

When boron deficiency symptoms of citrus were observed in a drought year, the boron content was below 10 ppm in fruit peel and leaves. The boron content when precipitation was abundant was 20 ppm in leaves and 14 ppm in peel, and no boron deficiency symptoms were observed. In an orchard where fruit had deficiency symptoms, the soil HWS-B content was 0.15 ppm in surface soil (0-15 cm) and 0.10 ppm in the subsoil (15 - 30 cm). This is regarded as the critical level (Fig. 1).

Citrus fruits deficient in boron are small in size, with thick peel and little juice. They are much harder than normal fruit.

Foliar symptoms of boron deficiency in citrus are not very characteristic. Any deficiency suspected on the basis of leaf symptoms should be confirmed by fruit symptoms. The first signs appear on the younger leaves, as water-soaked spots which become translucent. The veins tend to be thick, cracked and somewhat corky. The young leaves wilt and curl, and are a dull brownish-green color without any lustre. Dieback of leaf tips is common, and a gummy exudate may appear on the twigs and fruit pedicels. A study of the correlation between the available nutrients in the top 75 cm of soil, and the nutrient concentration in the leaf, showed no significant correlation for phosphorus and potassium, but a significant correlation for calcium, magnesium and boron. If the level of calcium (Mehlich's test) is above 500 ppm, and if the magnesium (Mehlich's) is more than 100 ppm and the HWS-B more than 0.20 ppm, the leaves may contain more than 2.5% Ca, 0.25% Mg and 25 ppm B.

Correction of Boron Deficiency

Applying boric acid to the soil at a rate of 40 - 120 g per tree (the trees were about 10 years old) was effective in correcting the boron deficiency problem. This was followed by soil application at a rate of 40 - 50 g of boric acid per tree every four years, to prevent a recurrence. Toxicity symptoms have occasionally been observed from excessive applications of boron. Leaves with symptoms have a boron concentration of more than 150 ppm. Levels as high as 200 - 650 ppm have been observed.

A foliar spray of 0.3% boric acid solution was also effective. However, a considerable amount of boron accumulated in the soil when spraying took place annually. For this reason, it is recommended that a foliar spray should not be applied every year.

Pineapple

Occurrence of Boron Deficiency

In Taiwan, boron deficiency in pineapple is widespread on moderately coarse to gravely alluvial soils derived from crystalline schist, where the reaction is slightly acid to alkaline (Su 1975). These soils are often very dry and have a low organic matter content. The boron deficiency is more serious when limestone materials are mixed into the soil, making it calcareous. The deficiency is also found in pineapple growing on more acid, strongly leached old red earth (pH 5.0), on tablelands derived from schist material, but the percentage of affected plants is much lower.

Diagnosis of Boron Deficiency

A water-soluble boron content of 1 - 1.5 ppm in the soil is regarded as the critical level for pineapple growth. The soil boron level should be checked after the first good rain.

Boron deficiency in pineapple is characterized by interfruitlet corking and reduced growth of fruits, with consequent cracking. The total solid content of affected fruits is very high (19.7%), and the acidity is very low (0.27%), compared to normal fruits (13.4% and 0.51%, respectively). A boron deficient pineapple plant is normal in color, but the leaf is thicker and harder, while the central leaves are twisted. The emergence of suckers and slips is reduced, and root development is also poor (Tseng 1966, cited by Su 1975).

Boron deficiency is much more pronounced in the ratoon crop than in the planted crop. The symptoms are milder in fields which have received an application of compost. Interfruitlet corking of pineapples was found to occur more severely in the ratoon crop, and when flower-forcing treatment was applied later in the year (in October rather than in September). This may be related to the scarcity of moisture in October, which would adversely affect the availability of boron in the soil.

Correction of Boron Deficiency

On neutral and weakly acid sandy soils, a liberal application of organic matter such as manure is the most effective way of improving the availability of boron. Ammonium sulfate is better than urea as a nitrogen source of nitrogen, since it has an acidifying effect.

Soil application of borax, at a rate of 12 - 14 kg/ha, will correct the boron deficiency. The boron is mixed with a basal dressing of fertilizer.

Borosilicate glass (sold in small fragments), which usually contains 3 - 6% boron, seems to be a suitable source of boron, especially in sandy soils and under high rainfall conditions, because of its slow-release nature.

For ratoon crops, it is recommended that farmers spray a 0.3% borax solution two or three times after the harvest of the planted crop, and before the floral differentiation of the ratoon crop in winter, i.e. in late August and early November.

HOW TO MEASURE SOIL BORON

The hot-water-soluble extraction procedure proposed by Berger and Truog (1939) has been widely used to measure available soil boron, and continues to be the basis of most soil testing for boron. Current methods typically include the use of a dilute electrolyte, such as a 0.01 to 0.02 M $CaCl_2$ solution, instead of water. Use of a dilute solution provides a clear, colorless extract in a large number of soils, which eliminates the need for charcoal as a decolorizing agent and also removes a source of negative error associated with B adsorption by charcoal during extraction (Gupta 1979, Parker and Gardner 1981). However, the color in the hot-

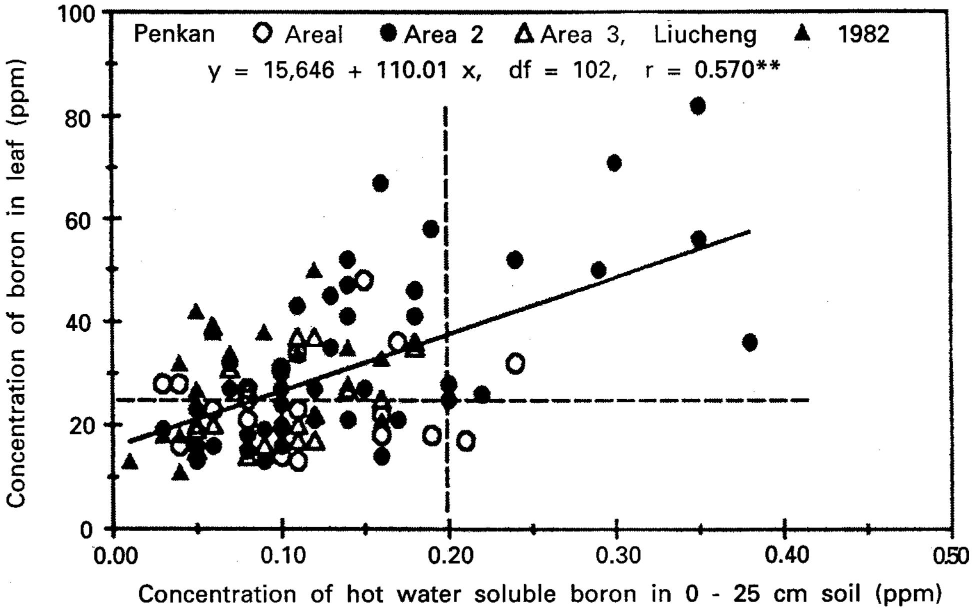

Fig. 1. The relationship between hot water soluble boron in orchard soils and boron concentration in citrus leaves.

source: Chang *et al.* 1992

water-soluble extracts is still a serious problem in a lot of soils of Taiwan, especially those with high organic matter contents, when B is determined by colorimetric procedures. This must be corrected (Ho 1988, Ho and Houng 1991), (Fig. 2).

Significant errors may occur if people using the hot-water-soluble extraction method are not aware of the following events:

- Possible contamination from using "low-boron glass" vessels;
- Variation due to variation in judging the time of refluxing and cooling; *and*
- Positive error caused by the color of the extracts in determining the level of boron by the azomethine-H method.

In order to deal with these difficulties, a number of alternative procedures have been developed. Ponnamperuma *et al.* (1981) used dilute HC1 as the extractant for determining available boron in rice soils. Cartwright *et al.* (1983) used 0.05 M mannitol in 0.01 M $CaCl_2$ as the extractant to study the available boron status of soils. An alternative method, which is simpler and less variable, uses a boron-specific ion exchange resin Amberlite IRA-743. This was developed for the extraction of available boron in Taiwan's agricultural soils (Juang 1991, Lee 1995).

The Amberlite IRA-743 resin had a very high affinity to boric acid or borate ions in a wide range of solution pH. This high affinity was not affected by the temperatures from 10°C to 80°C, or by the electrolytes or organic acids common in soil solutions. The amounts of soil boron extracted by the resin in a group of five soils to which various rates of boron had been applied showed a significant correlation ($P < 0.01$) to those extracted by hot water, and by 0.05 M mannitol – 0.01 M $CaC1_2$ extracting solution (Fig. 5). The method uses 20 g of soil shaken continuously with 1 g of resin in 100 ml of water for 48 hours. It is recommended as a routine procedure to assay available soil boron. However, more research is needed to examine the relationship of soil-extracted boron and plant response in the large, diverse group of soils that have been identified as deficient in boron.

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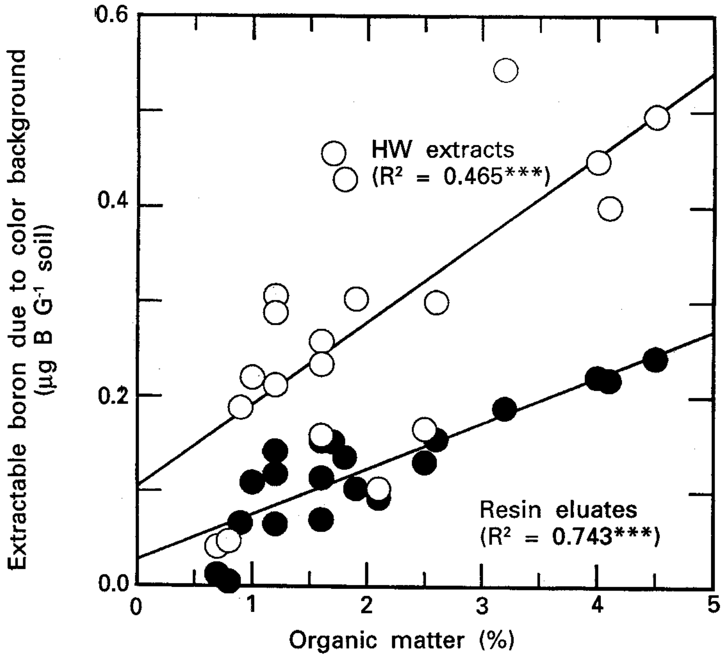

Fig. 2. Relationship between soil OM content and extractable boron due to color background in resin eluates and hot-water extracts

Source: Lee and Ho 1999

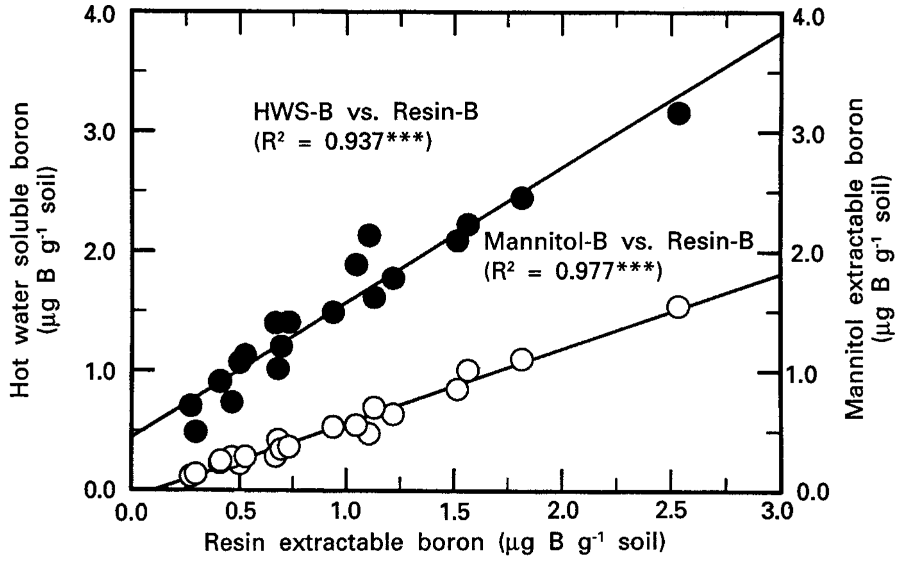

Fig. 3. Relationship between amounts of available boron extracted by resin, hot water, and mannitol-0.01 M $CaCl_2$ solution. (Significant at p = 0.001).

Source: Lee and Ho 1999

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