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BORON TOXICITY IN RICE

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BORON TOXICITY IN RICE[1]

ABSTRACT

Rice plants in some blocks at IRRI farm were affected by excess boron due to irrigation with high-boron deep well waters. Boron levels in IRRI well waters fluctuated depending on season and rainfall. High boron was a problem in the 1979, 1983, and 1984 dry seasons when rainfall was nil. Symptoms generally appeared when plants 8 wk after transplanting had more than 35 mg B/kg and the soil had more than 5 mg hot water soluble B/kg.

Yield reduction on high-boron soils varied among varieties and was unrelated to the severity of the typical necrotic symptoms. Yield reduction was estimated at 10-20% for tolerant varieties in blocks irrigated by the high-boron wells during dry seasons when rainfall was nil. Susceptible varieties would be more adversely affected. Some varieties tolerant of boron toxicity were also tolerant of salinity and alkalinity.

Dry plowing, use of low-boron surface water, and varietal tolerance are the best methods to make boron toxic soils more productive.

Boron toxicity was also observed in farmers' fields at Camp Eldridge in Los Baños, Laguna, and Balza in Malinao, Albay, both near geothermal areas and using deep well waters for irrigation.

The 0.05N HCl method of soil extraction for available boron correlated better with plant boron contents than the standard method presently in use.

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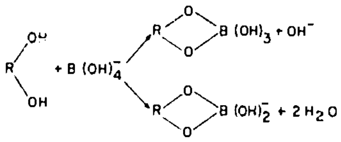
BORON TOXICITY IN RICE

Boron is an important micronutrient required for normal growth of plants. In soils of humid regions, B is associated with the highly insoluble mineral tourmaline from which it is slowly released (23). In low-rainfall regions, soluble borates may account for a large fraction of soil B (4). In these areas, soil B may accumulate with other salts in the profile or increase from irrigation with high-B water.

Soils formed from marine sediments are likely to contain more B than those formed from igneous rocks. Boron in marine clay sediments and in unrecognized weatherable minerals in rocks or deposits laid down in the sea, is high (up to 200 mg B/kg) whereas B in igneous rocks is lower (30 mg B/kg). Seawater has about 4.7 mg B/litre (31). Excess boric acid salts occur near volcanoes (8). Boron is also found in large amounts in plutonic rocks, and is detectable in some volcanic gases and in hot springs of some volcanic areas (17). Thus, B toxicity is most likely in arid irrigated areas (36), coastal areas (30), and volcanic areas (17). Boron toxicity is associated with the use of high-B irrigation water more often than with soils naturally high in B (18).

Below pH 6, B is present mostly as undissociated boric acid $B(OH)_3$ ($pK = 9.2$), and its plant uptake depends on mass flow. Above pH 6, $B(OH)_3$ is increasingly dissociated and hydrated to $B(OH)_4^-$ and its plant uptake becomes actively regulated (3, 26). Boron adsorption to organic matter, sesquioxides, and clay minerals increases with increasing pH, thus lowering B availability. It is probable that B is adsorbed by anion exchange to hydroxyl groups of organic substrates or sesquioxides as in the following (32), where R represents an organic group or a metal:



Drying of wetland rice soils lowers pH. Boron is thus desorbed and could then be readily leached out.

Reported ranges for soil available B (mg/kg) include 0.02-4.45 (9), 0.50-5.30 (11), 0.46-2.10 (25), 0.12-8.20 (24), 0.30-1.50 (28), 0.12-3.80 (34), 0.3-2.50 (37), and 0.38-4.67 (12).

Plant metabolic activity of B is similar to that for the P anion. Boron forms esters and polyhydroxyl compounds with polysaccharides, phenols, flavones, and nuclides. Boron influences carbohydrate metabolisms, N metabolism, membrane permeabilities, translocation and transpiration mechanisms, flowering, and pollen germination. Normal supply of B enhances dephosphorilization and synthesis of starch and cellulose (3) whereas excess B inhibits starch formation (33).

Crops vary widely in B uptake. Cereals and grains have only one-tenth the amount of B in root crops and other dicots (31). The ratio of toxic to adequate levels of B is the narrowest of the nutrient elements (12). For example, 0.5 mg B/litre in culture afforded good growth of sunflower whereas 1.0 mg P/litre was definitely toxic (7). Rice plants had no symptoms at 38 mg plant B/kg but symptoms were observed at 43-55 mg B/kg (21).

Boron uptake is closely related to the B concentration of the soil solution and the amount of water transpired. Alt and Schwarz (1) believe that B in high supply is passively distributed in the transpiration stream. This is the reason why B accumulates in leaf margins and toxicity symptoms follow leaf venation (16). Consequently, alfalfa leaves can have 75-98 mg B/kg whereas stems have only 22-27 mg B/kg (22). Sunflower leaf margins can have 322 mg B/kg but midrib areas from the same leaves have only 92 mg B/kg (33).

Very little work has been reported on B toxicity in rice. The first case of B toxicity on a coastal saline soil in a greenhouse experiment was reported by Ponnamperuma and Yuan in 1966 (30). The first field case of B toxicity in wetland rice was reported at IRRI farm by Ponnamperuma (29). The problem resulted because of long-term use of high boron deep well waters for irrigation. This review reports the work done at IRRI since 1979.

DISCOVERY OF BORON TOXICITY AT IRRI FARM

In the 1979 dry season (DS), rice plants in some blocks at IRRI farm exhibited brown necrotic spots on leaf tips and margins, symptoms characteristic of B toxicity. Analyses showed that these symptoms appeared when the plants contained > 35 mg B/kg about 8 wk after transplanting (WAT), and when the soils had > 5 mg hot water soluble B/kg. Other workers reported 5 mg B/kg (38), 4 mg B/kg in clay soils (3), and 3 mg B/kg (13, 7) as critical toxic limits. IRRI soils where plants had B toxicity symptoms in 1979 had much higher B than they did in 1977, indicating a buildup of soil B (Table 1). Further studies were then conducted to determine the reason for high B in some IRRI farm soils.

Analyses of irrigation waters in 1979 showed 1.9-5.3 mg B/litre. Waters with 2 mg B/litre are considered hazardous (3, 8, 15). Some IRRI deep wells pumped out water having higher B content than others. In these high-B wells, the water bearing zones tapped contained adobe, sometimes

Table 1. Boron content of soils in selected blocks at IRRI farm, 1977 and 1979.

Block	Boron content (mg/kg)	
	1977	1979
M7	9.3	11.0
M9	9.9	10.5
M11	7.6	12.1
M12	8.5	13.0
M16	7.8	9.9

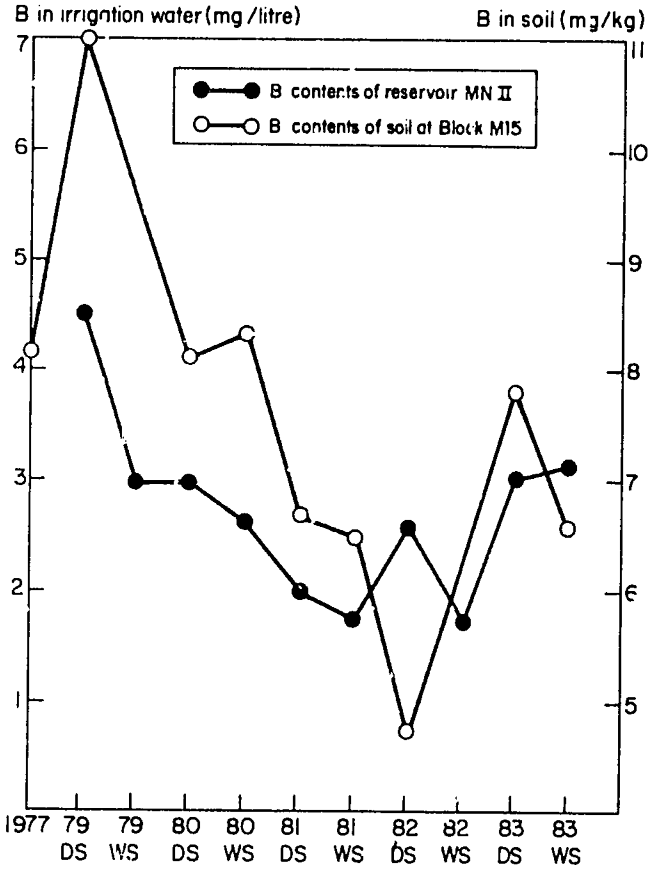
with borax chips. An unirrigated block in the Old Farm had the lowest available soil B. The amount of soil B in other blocks correlated with B contents of irrigation waters for those blocks (Fig. 1). Leaching experiments showed that IRRI deep well waters further increased soil B content whereas low-B water decreased it (Fig. 2). Boron toxicity in some blocks of the farm was thus traced to irrigation with high-B deep well waters. Nearby farmers' fields irrigated with surface water are not affected by B toxicity. River water dilutes B content of waters discharged from the farm. Thus, the problem of excess B is confined to some blocks within IRRI, and to rice fields similarly irrigated with deep well waters in geothermal areas.

ASSESSMENT OF DAMAGE TO WETLAND RICE

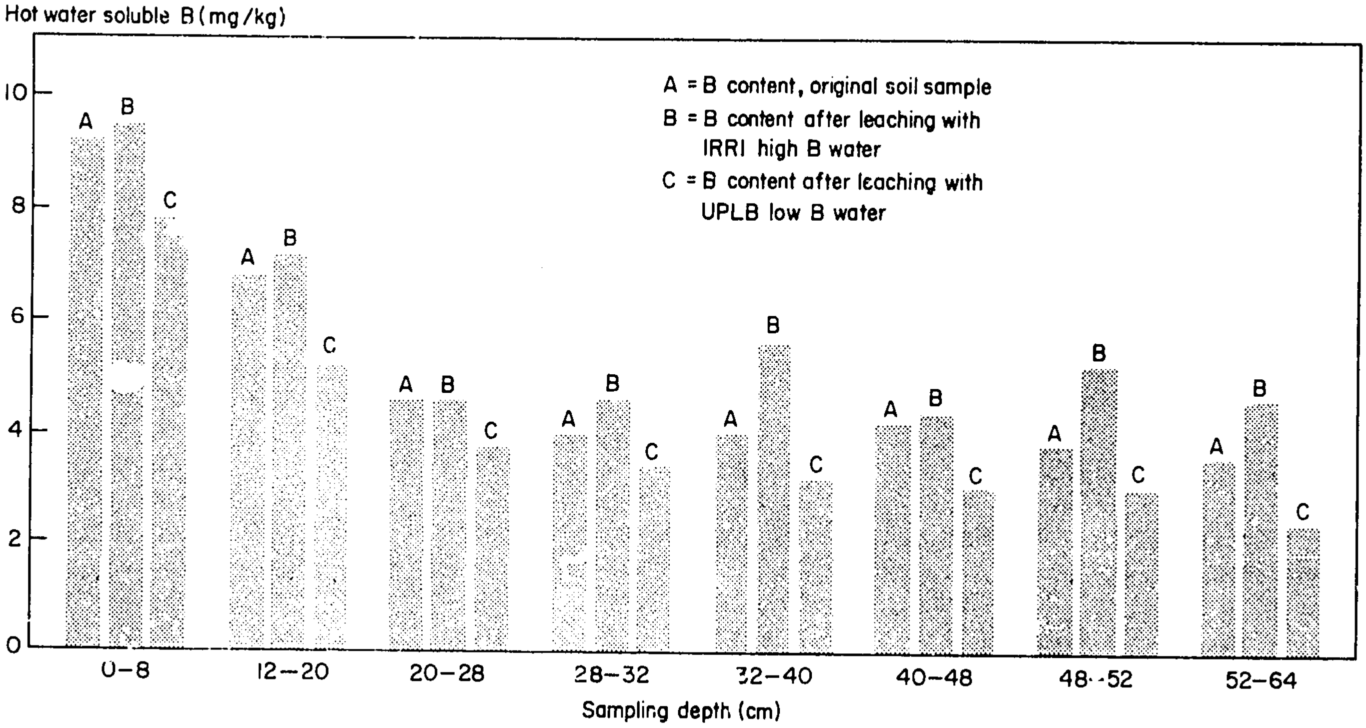
After B toxicity was confirmed, laboratory and greenhouse studies were conducted to assess possible damage to wetland rice.

Boron toxicity symptoms

Adding 20 mg B/kg to Maahas clay or to culture solution produced toxicity symptoms in rice in the greenhouse similar to those observed in the field. The symptoms start as light brown tips and marginal discoloration of older leaves. Two to four weeks later, depending on soil B content and variety, elliptical necrotic spots appear on these discolored areas. Finally, the entire leaf blade turns light brown and withers. Some varieties exhibit only tip and marginal discoloration. Vegetative growth is not markedly depressed unless the toxicity is severe. These symptoms are identical with those described by Lockard (20).



1. Changes in boron content of irrigation water at MNII and corresponding changes in soil boron content at Block M15, 1977-83.



2. Effect of leaching on boron content of soils from different depths in a high boron block at the IRRI Farm. (Core samples were obtained and leached by Dr. Tomar, Agronomy Department, 1979 wet season).

Critical levels for boron toxicity in rice

The next step was to determine the minimum amount of B that will produce toxicity symptoms and reduce rice yields. The literature contains conflicting reports about the critical limits for B toxicity in rice. USDA (36) reported that 1.5 mg B/litre in the saturation extract was toxic. Lockard (20) reported that 2 mg B/litre in the culture solution was harmful. Paliwal and Mehta (27), Ishizuka and Tanaka (14), Chakravarty et al (6), and Garg et al (10) reported B toxicity symptoms and yield depression in rice when grown in culture with 1.5-5.0 mg B/litre. Ponnamperuma and Yuan (30) found that severe B toxicity was associated with 9 mg B/litre in the interstitial solution.

In a greenhouse study using Maahas clay and culture solution treated with increasing B levels (0.5 to 20 mg/litre), plants grown with more than 2.5 mg B/litre in the mud extract or culture solution showed toxicity symptoms. This coincides with observations at the IRRI farm. The amount of soil B and plant B which will reduce rice yield 10% (critical levels as defined in [35]) differed according to variety and growth medium (Table 2). IR42 tolerated more B in plant tissue than IR36 and IR46. Plants grown in culture solution had higher B in the tissues than those grown in soil. This could account for previously reported discrepancies in critical levels for B toxicity.

Yield decline from use of high-boron irrigation water

A greenhouse experiment measured yield reduction of rice irrigated with high-B water. A tolerant variety, IR42, suffered a 17% decrease in grain yield when it had more than 3 mg B/litre in the mud extract throughout its growth period due to irrigation with high-B well water from the reservoir at block MNII (Table 3). Plant B content was 48 mg/kg at 8 WAT. A susceptible variety would have yielded worse. Some IRRI farm blocks had more than 3 mg B/litre mud extract in 1979, 1983, and 1984 DS.

Table 2. Boron concentrations in growth media and in plants 8 WAT, which resulted in 10% grain yield reduction of three varieties in greenhouse tests.

	IR36	IR46	IR42
B in growth media			
Soil (mg/kg)	3.8	6.3	3.8
Culture soln. (mg/litre)	0.7	1.3	6.8
B in 8 WAT plant			
Soil (mg/kg)	28	32	59
Culture soln. (mg/litre)	53	60	120

RECLAMATION STUDIES

In laboratory tests, adding Fe and Al hydroxides, known to adsorb B, failed to reduce B contents in IRRI irrigation waters to normal levels. Boron contents of these waters are already near the equilibrium concentration of B in contact with precipitated Fe and Al hydroxides. Thus, no further decrease can be expected by adsorption reactions.

Boron removal from irrigation water by a strongly basic anion exchanger (Rexyn AG) was as high as 70% for the first few fractions. However, B retention was temporary because it was sensitive to increase in pH. pH is bound to increase when irrigation water is passed through a strongly basic anion exchanger unless the water is previously softened or passed through a cation exchanger. Considering the volume of irrigation water needed, it would be very expensive and impractical to use ion exchange to lower the B content of IRRI farm waters.

Organic matter could complex B and aid in its release from the soil upon leaching. In a greenhouse test, adding compost, chicken manure, and gypsum, with leaching, gave the highest grain and straw yields on a high-B soil (Table 4). In the same test, adding turmeric, an organic material containing curcumin which complexes B, failed to improve yield.

Leaching experiments showed it was more difficult to remove B from continuously wet soils than from previously dried ones. After 6 wk of leaching at 1 cm/d, B in the mud extract from a puddled soil was 4.2 mg/litre while that from

Table 4. Effect of organic matter, turmeric, sulfur, gypsum, and leaching on the growth of rice on a high-boron soil in the greenhouse, 1980 DS.

Treatment	Leaching		Grain wt (g/pot)	Straw wt (g/pot)
	Yes	No		
Control		x	80.6 abcd	154 bcd
	x		69.7 cd	133 fg
Straw		x	81.8 abc	150 cde
	x		76.7 abcd	129 g
Compost		x	72.8 abcd	148 def
	x		89.2 a	172 a
Chicken manure		x	71.7 bcd	138 fg
	x		86.1 ab	170 a
Turmeric		x	70.6 bcd	134 fg
	x		74.3 abcd	148 def
Sulfur		x	65.8 d	159 abcd
	x		77.5 abcd	165 abc
Gypsum		x	85.1 abc	134 fg
	x		88.2 a	167 ab

Table 3. Effects of B content of water source and leaching on plant B, soil solution B, and yield of IR42 in the greenhouse.

Source	B	Leaching	Plant B (mg/kg)	Soil solution B (mg/litre)	Grain yield (g/pot)	Relative yield (%)	Yield decline (%)
Tap	0.9	no	31 b	1.5	52 a	100	–
Tap	0.9	yes	28 b	0.7	55 a	106	–
Reservoir	3.0	no	52 a	3.9	43 b	83	17
Reservoir	3.0	yes	49 a	3.2	45 b	87	13

the dried soil was 3.2 mg/litre. Boron contents of leachates from the dried soil were higher, indicating that more B was being removed than from the puddled soil. Thus, dry plowing could lessen soil B by facilitating leaching.

Leaching with low-B tap water reduced the B content of the soil and soil solution and produced higher yield. The use of low-B water for irrigation, even without leaching, could improve yields (Table 3). This shows that the best remedy for B toxicity is to use low-B surface water.

Good quality surface water could easily leach excess B past the root zone especially at the IRRI farm where water temperatures rise up to 40°C. Laboratory tests showed that the amount of B which can be removed from a soil increases linearly with water temperature. In one cropping season in the greenhouse, extractable soil B was reduced from 12.2 to 6.8 mg/kg just by using low-B irrigation water, even without leaching. Thus, B toxicity at the IRRI farm is nonexistent in the WS and minimal even in the DS, if rainfall is significant.

Where low-B water is not available, rice varieties tolerant of B toxicity may be adopted.

VARIETAL TOLERANCE TO EXCESS BORON

Greenhouse and field tests revealed that rice varieties react to excess B differently in symptoms and in yields. Some varieties do not exhibit the classic necrotic spots; leaf tips and margins only turn yellow or light brown. So far, 48 such varieties have been identified in our screening tests. Field workers checking B toxicity should be aware of both types of symptoms.

Number and size of necrotic spots were unrelated to yield reduction. Severity of foliar symptoms was not a good index of susceptibility to B toxicity. Varieties and lines that have performed consistently well in tests are IR38, IR42, IR46, IR48, IR54, IR5657-33-2-1-2, IR8192-200-3-1-1-2, IR8608-298-3-1-1-2, IR9129-209-2-2-2-3, IR9217-58-2-2, IR9884-54-2-2, IR13423-10-2-3, IR13426-19-2, IR21820-154-3-2-2-3, and IR29723-143-3-2-1. Some of these varieties also tolerate salinity and alkalinity and are expected to do well on saline and alkali soils where B toxicity is most likely. Tolerance for excess B confers a yield advantage of about 2 t/ha over susceptible varieties.

Field tests of yield reduction

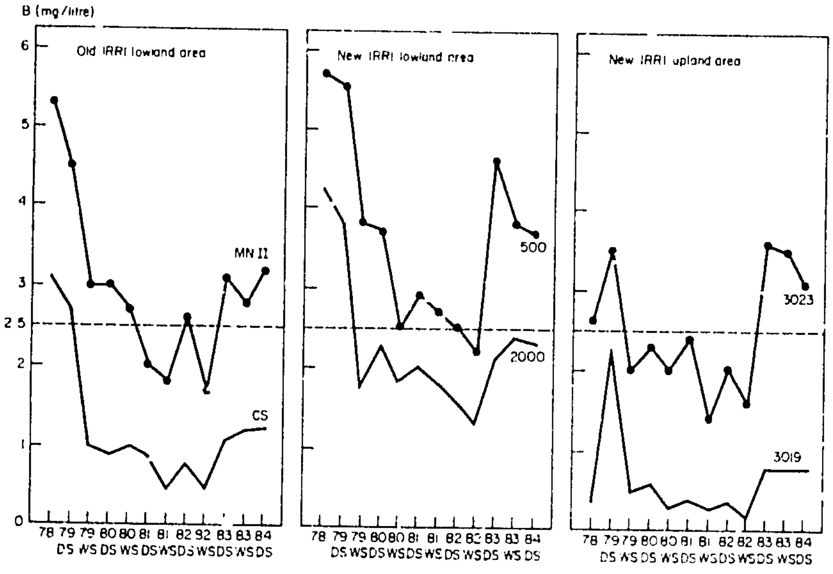
When grown on a soil having 17 mg B/kg, grain yields of tolerant varieties were reduced 0-35% from those on a soil having 8.5 mg B/kg. Yields of susceptible varieties were reduced 45-76%. Vegetative growth was not markedly affected by excess B. Other workers have found that excess B inhibits the formation of starch from sugars (33). This explains why it hinders grain filling and not leaf formation.

When B was maintained at 3-4 mg/litre in the mud extract throughout the growth period, yields of tolerant varieties IR42 and IR21820-154-3-2-2-3 were reduced about 15%. Yield reduction is expected to range from 10 to 20% when a tolerant variety is grown in a block where irrigation water B is more than 3 mg/litre throughout the growth period in the DS.

SURVEYS OF BORON TOXICITY AT IRRI FARM

At IRRI farm, B toxicity symptoms are more severe in the DS than in the WS. That is because in the DS, B contents of well waters are higher and there is little rainwater to dilute the high B. Because B is passively distributed with the transpiration stream (3), higher transpiration rates in the DS also account for more severe B toxicity. Necrotic spots are most prominent at about panicle initiation.

Boron contents of the IRRI reservoirs are being monitored. When B levels in reservoirs at blocks MNII, 300, 500, and 3023 reach 2.5 mg/litre in the DS, B toxicity symptoms start to appear at blocks M, N, 400-600, and UB. These reservoirs have highest B contents (Fig. 3), sometimes reaching 4.7 mg/litre, the B content of seawater (31).



3. Trends in boron content of irrigation waters from reservoirs with the highest and lowest B content in three areas in the IRRI Farm, 1979-84 (Boron analysis by J. L. Solivas, M. C. Calimon, M. T. C. Cayton, and N. B. Uy).

Boron levels in IRRI irrigation waters fluctuate depending on season and amount of rainfall. Figure 3 shows how B contents varied from 1979 to 1984 in some reservoirs. Because B levels in irrigation water fluctuate, the severity of symptoms and subsequent yield reductions depend on how long B content of waters remains high during the growth period.

The problem was most severe in the 1979, 1983, and 1984 dry seasons, when B in the mud extract was often more than 3 mg/litre, enough to reduce yields 10-20% in resistant rice varieties and more for susceptible ones. In 1981 and 1982 dry seasons, however, B toxicity at the farm was minimal because rainfall was high. Data on B analysis of mud extracts and plants from affected sites are summarized in Table 5.

The sites where the maximum yield trials (MYT) at the IRRI farm are being conducted had toxic B levels in 1983 and 1984 dry seasons, especially in 1983. Mud extract and plant B contents were above the critical limits (Table 6). Excess B could be one of the reasons for lower yields at these sites at IRRI as compared with a MYT site in a farmer's field in 1983 DS (Table 7). In 1983 DS, highest mean yields at the IRRI MYT sites were obtained from IR42 and IR21820-154-3-2-2-3, top yielders in our B toxicity performance tests. IR36 and IR9729-67-3, susceptible to excess B in the same performance tests, gave the lowest grain yields. In the farmer's field, which was not affected by B toxicity, IR36 and IR21820-154-3-2-2-3 gave highest yields.

BORON TOXICITY IN AREAS OUTSIDE OF IRRI

Deep well irrigation waters in geothermal and hot spring areas are expected to have high B. Thus, a search for B toxicity was made in farmers' fields irrigated with deep well water in geothermal areas.

As early as 1977, B toxicity, together with NPK deficiency, was observed to limit rice growth on a peat soil from Camp Eldridge, Los Baños, Laguna (19). In that greenhouse experiment, the soil was obtained from a farmer's field where B toxicity symptoms were similarly observed in 1980. Water welling out of an abandoned rice field at this site was hot and had 12 mg B/litre. The field was converted into a fishpond after rice cultivation failed. Grasses in the swamps had burned tips. Available soil B was 38 mg/kg.

In a nearby rice field, farmers noted more than 50% decrease in yield after they shifted to deep well irrigation water due to scarcity of groundwater. Available soil B was 25 mg/kg and the irrigation water had 7.4 mg B/litre. Rice plants were severely stunted with brown necrotic blotches along leaf margins. Boron content of plants was higher than in those at IRRI (Table 8). Upland crops growing in the vicinity also had brown necrosis along leaf margins. Tissue analysis confirmed B toxicity (Table 9).

In yield trial experiments on a peat soil at Balza in Malinao, Albay, a few kilometers from a geothermal plant, rice plants had typical B toxicity symptoms at 8-10 WAT (J. L. Solivas, IRRI, pers. comm.). Plant analysis confirmed B content above the critical limit. Although Zn deficiency probably limited growth more, excess B was likely a secondary reason for low yields.

Table 5. Boron content of mud extracts and of plants 8 WAT, from IRRI blocks where B toxicity symptoms were observed 1980-84.

Year	Block	B in mud extract (mg/litre)	B in 8 WAT plants (mg/kg)
1980	N	3.9	42
	400	3.6	40
1983	L	2.4	44
	UB	3.3	50
	250	3.8	62
	300	3.9	63
	400	4.0	58
	500	4.0	79
	600	4.9	74
1984	L	3.5	60
	M	5.2	75
	N	5.5	64
	100	5.0	70
	200	4.3	77
	300	4.5	53
	500	5.2	72
	600	6.2	76
	800	3.8	38

Critical limit for appearance of B toxicity symptoms: 2.5 mg B/litre in mud extract, 35 mg B/kg in 8 WAT plants.

Table 6. Mud extract B, plant B, and scores for B toxicity symptoms of some varieties used in the maximum yield experiments at the IRRI farm, 1984 DS.

	B toxicity	Symptoms score	8 WAT plant B (mg/kg)
N14	(3.2 mg/litre mud extract B)		
	IR36	1.3	58
	IR42	3.3	79
	IR29723-143	2.7	61
UB2	(5.0 mg/litre mud extract B)		
	IR42	3.8	108
	IR58	1.0	42
	IR21820-154	2.0	46

Although B toxicity was a problem in these sites, yield reduction did not always correlate with severity of necrotic symptoms. Critical limit for 10% yield reduction: 28 mg/kg plant B for IR36, 59 mg/kg plant B for IR42.

SIMPLE METHODS OF EXTRACTION FOR ASSAY OF AVAILABLE SOIL BORON

In these studies, hundreds of soil extractions for B analysis were done using the standard reflux method of Berger and Troug (2). This method uses refluxing equipment, at 20-30 samples/d. Because this extracting procedure was not applicable to routine soil testing, two simpler methods were compared with the reflux method in replicated greenhouse and laboratory trials.

Table 7. Grain yields of some rices at the maximum yield trial sites, IRRI farm, compared with their yields in a farmer's field at Talavera, Nueva Ecija. Agronomy Department, 1983 DS.

Variety	Nitrogen level	Grain yield (t/ha) N13/N14	Grain yield (t/ha) UB2	Grain yield (t/ha) Talavera	% yield reduction[a]	Variety's reaction to B toxicity[b]
IR9729-67-3	84	6.0	5.3	6.8		
	126	6.3	5.4	7.5		
	168	6.3	4.8	7.0		
	Mean	6.2	5.2	7.1	20	S
IR58	84	5.1	5.7	6.8		
	126	6.2	5.7	7.3		
	168	6.6	6.0	7.4		
	Mean	6.0	5.8	7.2	18	S
IR36	84 + 30	6.2	5.8	8.5		
	126 + 30	5.9	5.3	8.3		
	168 + 30	5.4	4.8	8.2		
	Mean	5.8	5.3	8.3	33	S
IR21820-154	84 + 30 + 30	7.6	8.9	8.6		
	126 + 30 + 30	7.4	7.4	8.6		
	168 + 30 + 30	6.2	5.9	8.3		
	Mean	7.0	7.4	8.5	15	T
IR42	84 + 30 + 30	8.0	6.7	7.3		
	126 + 30 + 30	6.9	6.8	7.6		
	168 + 30 + 30	6.5	6.7	7.1		
	Mean	7.1	6.7	7.3	5.4	T
Mean site yield for 10 varieties		6.4	5.9	7.5		

[a] % yield reduction = $\dfrac{\text{yield at Talavera} - \text{average mean yield at N13/N14 and UB}_2}{\text{yield at Talavera}} \times 100$.

[b] S = susceptible, T = tolerant.

Table 8. Boron content of rice plants showing toxicity symptoms and boron content of the soil in Barrio Bambang, Los Baños, Laguna, Philippines, 1979 DS.

	B (mg/kg) Plant	B (mg/kg) Soil
1. Stunted growth, few plants with necrotic spots	73	22
2. Stunted growth, most plants with necrotic spots	121	26
3. Stunted growth, necrotic spots, some plants dead	188	29

Table 9. Boron content of leaves of crops showing B toxicity symptoms taken from a high-boron area (15 mg/kg) in Barrio Bambang, Los Baños, Laguna, Philippines, 1979 DS.

Crop	B (mg/kg)
Cassava	533
Gabi	464
Coconut	228
Banana	205
Sugarcane	51
Guava	45

Table 10. Correlations between the standard reflux method and the hotplate and 0.05 N HCl methods, in measuring available boron.

Hot plate vs reflux	r = 0.971**
0.05 N HCl vs reflux	r = 0.956**

Boron was extracted from 53 soil samples by 3 methods:

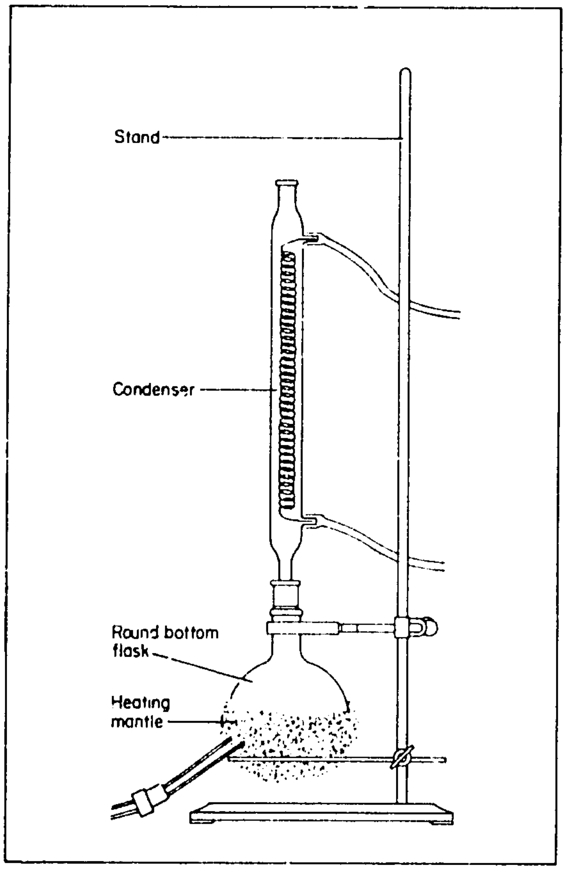
1. Reflux method. Twenty g portions of 80-mesh soil samples treated with 0.5 ml 10% $BaCl_2$ solution and 40 ml water were refluxed for 5 min in a round bottom flask placed on a heating mantle (Fig. 4). The suspensions were then filtered.
2. Hot plate method. The samples were treated as in 1 but instead of the reflux apparatus, 200-ml Erlenmeyer flasks with funnels were used (Fig. 5). The suspensions were then filtered.
3. 0.05 N HCl. Ten g portions of 80-mesh soil samples were treated with 20 ml of 0.05 N HCl. The suspensions were shaken on a horizontal shaker for 5 min and then filtered.

Filtrates obtained by these three methods were analyzed for B by the curcumin oxalic acid method (5).

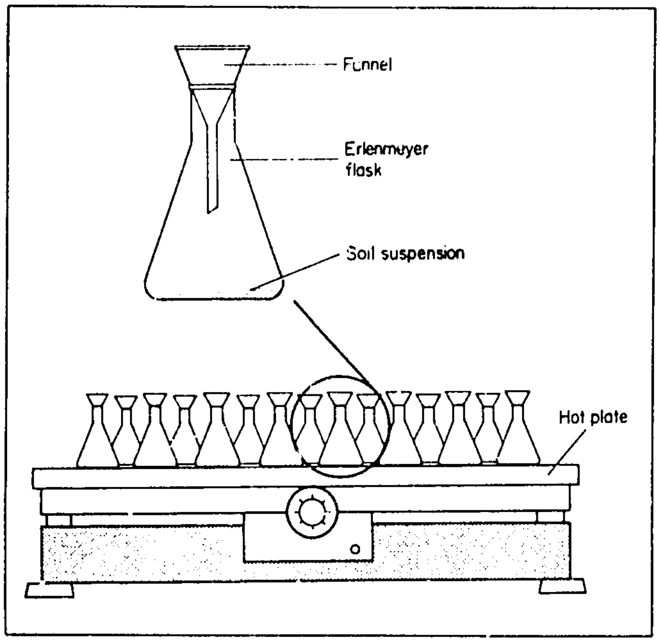
The soils of widely differing characteristics used in this study were obtained from 38 sites in the Philippines and 15 blocks at the IRRI farm. They varied in pH from 4.1 to 8.0 and in available B from 0.3 to 24.5 mg/kg. On 18 of the 53 soils, IR42 showed B toxicity symptoms. All 18 soils had > 4 mg/kg 0.05 N HCl extractable B and > 5 mg/kg hot water extractable B. Boron values obtained by both methods correlated highly with the standard reflux method (Table 10). Plant B contents also correlated highly with soil B extracted by the three methods (Table 11). The two simpler methods save time and effort. Both are well suited for use in routine soil testing laboratories.

Table 11. Correlations between plant boron levels at 8 WAT and 3 methods of measuring available boron.

Plant B vs reflux	r = 0.842**
Plant B vs hot plate	r = 0.842**
Plant B vs 0.05 N HCl	r = 0.909**



4. Reflux method for extracting available boron in soils.



5. Hot plate method for extracting available boron in soils.

SUMMARY OF RESULTS AND RESEARCH NEEDS

- Boron toxicity in some blocks of the IRRI farm is caused by irrigation with high-boron deep well waters. The problem is more severe in the DS because of higher B contents in well water, lack of rainfall to dilute high B water, and greater plant transpiration.
- The critical limits for appearance of toxicity symptoms in the field at 8 WAT are: >5 mg/kg hot water extractable soil B, >4 mg/kg 0.05 N HCl extractable soil B, >2.5 mg B/litre in the mud extract or irrigation water, and >35 mg/kg plant B.
- Varieties differ in showing toxicity and in yield reduction with excess B. Severity of necrotic symptoms is not a good indicator of susceptibility. Tolerant varieties could have 10-20% yield reduction in the field when the mud extract has at least 3 mg B/litre throughout the growth period. Susceptible varieties would be more adversely affected.
- Some varieties tolerant of salinity and alkalinity were found also tolerant of excess B. Examples are IR46, IR5657-33-2-1-2, IR9884-54-2-2, and IR13423-10-2-3.
- Dry plowing and diluting high-B reservoirs with low-B irrigation water is the best method to reclaim high-B soils at the IRRI farm. Steps are already being taken to look for low-B water zones which may be tapped for this purpose.
- Boron toxicity limits yields in farmers' fields near Camp Eldridge in Los Baños, Laguna, and Balza in Malinao, Albay. Both sites, which are near geothermal areas, use deep well water for irrigation.
- Methods for soil available B extraction suitable for routine soil testing have been developed. The 0.05 N HCl method is recommended because it correlates highest with plant B uptake.

We now have a better understanding of the causes, occurrence, degree of damage, and appropriate remedies for B toxicity in wetland rice. These findings could aid in interpreting yield trends at the IRRI farm and other geothermal areas irrigated with high-B deep well waters. Using tolerant rice varieties can improve productivity in soils with B toxicity. Studies are under way:

- to determine the growth stage when plants are most susceptible to excess B,
- to determine if excess B has an indirect adverse effect on microbiological processes related to soil fertility,
- to continue screening rices to identify those tolerant of excess B, and
- to continue monitoring B toxicity at IRRI farm.

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REFERENCES CITED

1. Alt, V. D., and W. Schwarz. 1973. Bor-Toxizitat, Bor-Aufnahme und Bor-Verteilung bei jungen Gurkenpflanzen unter dem Einfluss der N-form. Plant Soil 39(2):277-283.
2. Berger, K. C., and E. Troug. 1939. Boron determination in soils and plants. Ind. Eng. Chem. Anal. Ed. 11:540-545.
3. Bergmann, W. 1983. Nutritional disorders of crop plants. VEB Fisher Verlag, Stuttgart.
4. Bertramson, B. R. 1955. Soil chemistry notes. Student Book Corp., Pullman, Wash. p. 349-362.
5. Bingham, F. T. 1982. Boron. *In* Methods of soil analysis. Part 2. American Society of Agronomy, Inc., Madison, Wisconsin.
6. Chakravarty, S. K., H. Sinha, and K. P. Singh. 1979. Note on boron nutrition of cereals and legumes in a sand culture study. Indian J. Agric. Sci. 49(5):382-383.
7. Eaton, S. V. 1940. Effects of boron deficiency and excess on plants. Plant Physiol. 15(1):95-105.
8. FAO/UNESCO. 1973. International source book. Irrigation, drainage and salinity. V. A. Kovda, C. van der Berg, and R. G. Hagan, eds. Hutchinson, London.
9. Galczyska, B. 1967. Occurrence of boron in soils and plants of the coastal region. Pam. Pulawski No. 30:115-134 [Pl. e.v.]. Soils Fert. Abstr. 32(5):424. Abstr. #3369.
10. Garg, O. K., A. N. Sharma, and G. R. Kona. 1979. Effect of boron on the pollen vitality and yield of rice plants. Plant Soil 52(4):591-594.
11. Grewal, J. S., D. R. Bhumbla, and N. S. Randhawa. 1969. Available micronutrient status of Punjab, Haryana and Himachal soil. J. Indian Soc. Soil Sci. 17(1):27-31.
12. Gupta, U. C. 1979. Boron nutrition of crops. Adv. Agron. 31: 273-307.
13. Hesse, P. R. 1971. A textbook of soil chemical analysis. Chemical Publishing Co., New York.
14. Ishizuka, Y., and A. Tanaka. 1962. Inorganic nutrition of the rice plant. 7. Effect of boron, zinc and molybdenum level of the culture solution on yield and chemical composition of the Plant. J. Sci. Soil Tokyo 33:93-96. [J] Soils and Fert. Abs. 27(4):333. Abs. No. 2431.
15. Kanwar, J. S., and N. S. Randhawa. 1972. Micronutrient research in soils and plants in India. Indian Council of Agricultural Research. New Delhi.
16. Kohl, H. C., Jr., and J. J. Oertli. 1961. Distribution of boron in leaves. Plant Physiol. 36(4):420-424.
17. Krauskopf, K. B. 1972. Geochemistry of micronutrients. *In* Micronutrients in agriculture. J. J. Morvedt, P. M. Giordano, and W. H. Lindsay, eds. Madison, USA.
18. Kubota, J., and W. H. Allaway. 1972. Geographic distribution of trace element problems. *In* Micronutrients in agriculture. J. J. Morvedt, P. M. Giordano, and W. H. Lindsay, eds. Madison, USA.
19. Lantin, R. S. 1976. Factors limiting the growth of rice on a peat soil. Proceedings of the 7th Crop Science Society of the Philippines Scientific Meeting.
20. Lockard, R. G. 1959. Mineral nutrition of the rice plant in Malaya. Department of Agriculture, Kuala Lumpur, Malaysia.
21. Lockard, R. G., I. C. Ballaux, and E. A. Liongson. 1970. Response of rice plants grown in four potted Luzon soils to additions of boron, sulfur and zinc. Philipp. Agric. 54:144-158.
22. Miller, D. A., and R. K. Smith. 1977. Influence of boron on other chemical elements in alfalfa. Commun. Soil Sci. Plant Anal. 8(6):465-478.
23. Mitchell, R. L. 1964. Trace elements in soils. Pages 320-368 *in* Chemistry of the soil. Edition 2. F. R. Bear, ed. Reinhold Publ. Corp., New York.
24. Nathani, G. P., H. S. Shankaranarayana, and C. M. Mathur. 1970. Status of water soluble boron in the soils of Rajasthan. J. Indian Soc. Soil Sci. 18(3):341-344.
25. Nathani, G. P., Q. Uzzama, and H. S. Shankarnarayna. 1969. Water soluble boron in irrigated medium black soils. J. Indian Soc. Soil Sci. 17(1):59-62.
26. Oertli, J. J., and E. Grgurevic. 1975. Effect of pH on the adsorption of boron by excised barley roots. Agron. J. 67:278-280.
27. Paliwal, K. V., and H. K. Mehta. 1973. Interactive effect of salinity, SAR and boron on the germination and growth of seedlings of some paddy rice varieties. Plant Soil 39(3):603-609.
28. Panin, M. S., and V. I. Shchetinina. 1974. [The boron content of plants in the semipalatinsk region of Kazakstan]. Agrokhimiya (1974) No. 1, 196-112 [Ru] Semipalatinsk Pedagogicheskii Institut, USSR. Soils Fert. Abstr. 37(12):368. Abstr. 3646.
29. Ponnamperuma, F. N. 1979. Soil problems in the IRRI Farm. Paper presented at a Thursday seminar, 8 November 1979, International Rice Research Institute, Los Baños, Laguna, Philippines.
30. Ponnamperuma, F. N., and W. L. Yuan. 1966. Toxicity of boron to rice. Nature 211:780-781.
31. Russell, E. W. 1973. Soil conditions and plant growth. 10th ed. Longman Inc., New York.
32. Schachtschabel, P., H. P. Blune, K. H. Hartge, and U. Schwertunann. 1982. Lehrbuch der Bodenkunde. F. Eluke Verlag, Stuttgart.
33. Scott, E. G. 1960. Effect of supra optimal boron levels on respiration and carbohydrate metabolism of Helianthus annus. Plant Physiol. 35(6):653-661.
34. Singh, R. M. 1973. Relationship between boron content of irrigation waters and soils. Indian J. Agron. 18(3):341-343.
35. Ulrich, A., and F. J. Hills. 1967. Principles and practices of Plant Analysis. Pages 11-24 *in* Soil testing and plant analysis. Part II. SSSA Spec. Publ. Ser. 2. Soil Science Society of America, Madison, Wisconsin.
36. United States Department of Agriculture, Salinity Laboratory Staff. 1954. Saline and alkali soils. Washington, D. C.
37. Whetstone, R. R., W. O. Robinson, and H. G. Byers. 1942. Boron distribution in soils and related data. USDA Tech. Bull. 797.
38. Wolf, B. 1971. The determination of boron in soil extracts, plant materials, composts, manures, water and nutrient solution. Commun. Soil Sci. Plant Anal. 2(5):363-374.

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