FURTHER EVIDENCE THAT BORON IS ESSENTIAL FOR THE GROWTH OF LETTUCE[1]

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(WITH EIGHT FIGURES)

In a previous report (**2**) it was shown that boron is essential for the growth of several varieties of lettuce; and that when it was excluded from the mineral nutrient solution, a severe deficiency disease resulted which was characterized by malformation of the more rapidly growing leaves, spotting and burning of the leaf tips, and death of the growing point of the plant. A similar condition of lettuce was described by STONE and SMITH (**3**) as "top-burn." They considered the cause of the disease to be physiological and promoted by unfavorable surroundings. LE CLERG (**1**) measured leaf temperatures, but could not establish a relation between temperature and tip burning. The writers have further investigated the disorder, from the standpoint of a nutritional deficiency.

The influence of various boron compounds in preventing the burning of lettuce leaves was studied in both sand and water cultures. Control of the exact boron content of cultures was obtained by the addition of definite quantities of pure boron compounds to boron-free media. A dilute Pfeffer's solution, to which small quantities of manganese, copper, and zinc were added, supplied the basal mineral nutrients for both sand and water cultures. The salts composing the basal solution were proved to be free of boron by spectroscopical examination. Sand was purified by digestion with hot hydrochloric acid, followed by removal of chlorides with distilled water. Distilled water required for the preparation of cultures, growth of plants, purification of sand, and rinsing of containers was condensed in quartz. Porcelain dye pots and special acid-resistant jars with perforated lids were used as containers for the sand and water cultures respectively. No evidence of boron contamination from the use of these containers was observed.

Lettuce seeds were germinated in purified sand, and transferred to sand or water cultures containing, with the exception of boron, all elements known to be essential for plant growth. Severe boron deficiency, as indicated by severe injury to the leaf tips, developed in from two to four weeks, depending upon the variety, amount of light, and type of culture used.

[1] Contribution from the Department of Chemistry of the Kentucky Agricultural Experiment Station.

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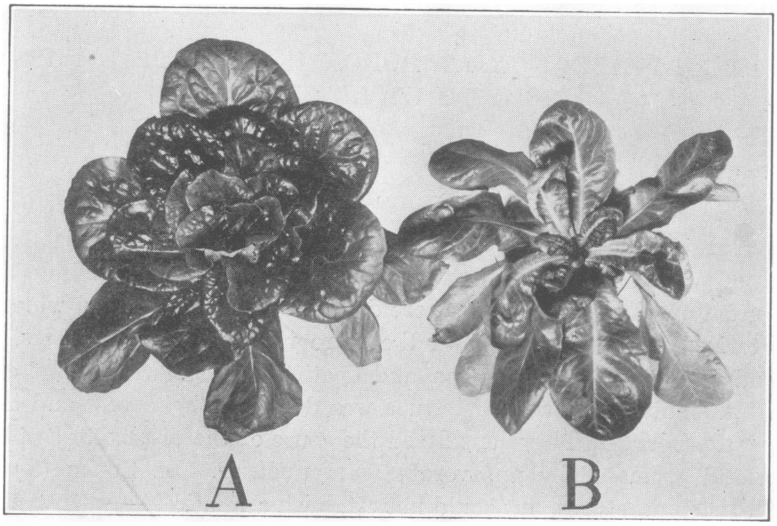

FIG. 1. Effect of boron on growth and development of lettuce plants: *A*, plant grown in sand containing 0.5 p.p.m. boron; *B*, plant not supplied with boron.

The first symptoms of boron deficiency were a retardation of growth and malformation of the younger leaves. Dark spots then appeared on the margin of the growing leaves, usually at the tip. Marginal growth was

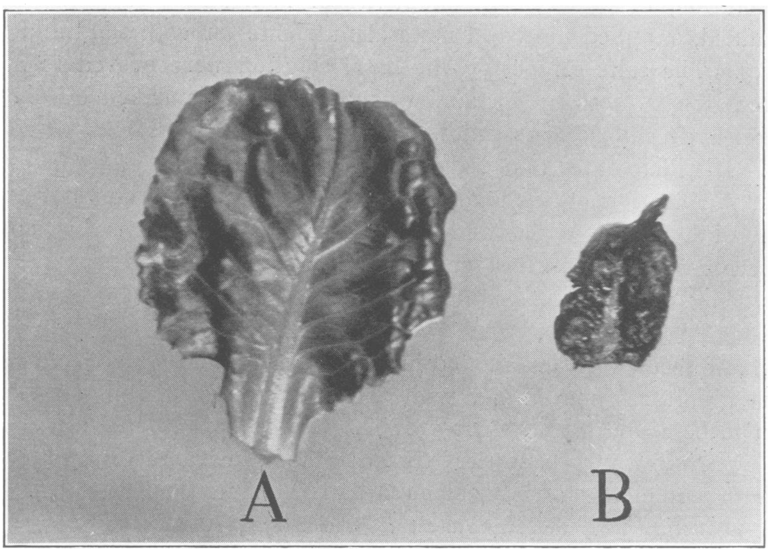

FIG. 2. Effect of boron deficiency on leaf development: *A*, leaf from normal plant; *B*, leaf from plant showing severe boron deficiency.

suspended, resulting in a folding back of the leaf tip. Normal and deficient plants at this stage are shown in figure 1. The spots increased in size and number, involving the entire leaf tip and giving it a scorched appearance. Figure 2 shows leaves from normal and deficient plants of the same age. The older leaves are not noticeably affected by the absence of boron; but all young leaves, from those first affected to the growing point itself, are involved, resulting finally in the destruction of the meristem tissue and consequently in the death of the plant (fig. 3).

FIG. 3. Growing point of lettuce plant showing severe boron deficiency.

The addition of a small quantity of boron to the culture before the death of the growing point relieved the condition and resulted in the production of normal leaves from the growing point. The addition of boron compounds after the death of the growing point resulted in growth from lateral buds in the leaf axils. Figures 4–6 show the results of continued additions of boron to the media after the development of severe deficiency, allowing the plant to make very satisfactory growth to maturity. Plants that were retarded in early growth by the absence of boron did not attain the same size or weight at maturity as did normal plants (positive controls).

Small quantities of boric acid, boro-silicate (powdered Pyrex glass), and borates of potassium, sodium, calcium, manganese, copper, and zinc were found to be effective in preventing injury to lettuce leaves.

To ascertain the optimum concentration of boron for the growth of lettuce, cultures in triplicate were treated with boric acid varying the boron

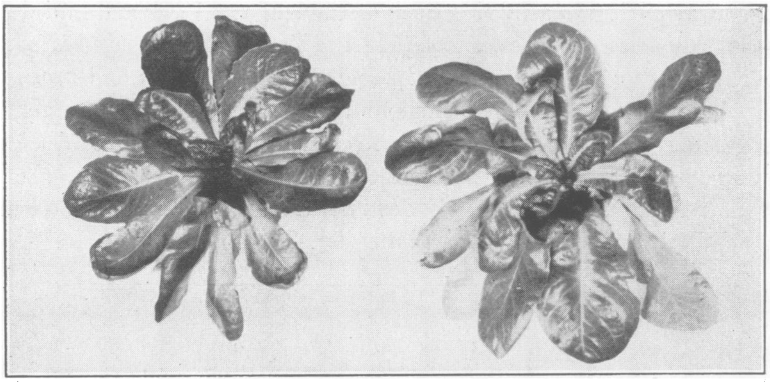

FIG. 4. Lettuce plants in which boron deficiency had caused death of the growing point. Boric acid was added to the one on the left at this time.

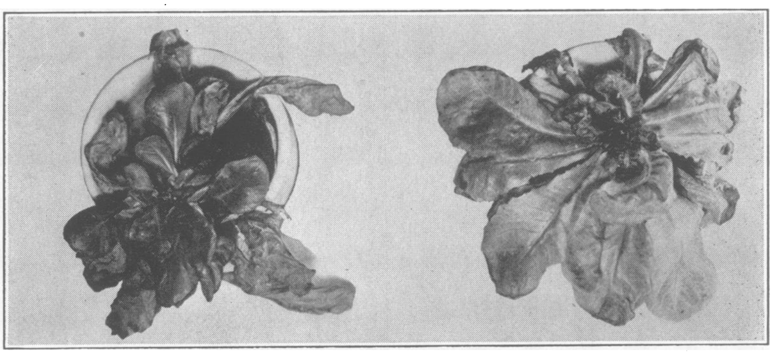

FIG. 5. Same plants as in figure 4, 14 days later. Growth has been resumed from axillary buds in the plant receiving boric acid.

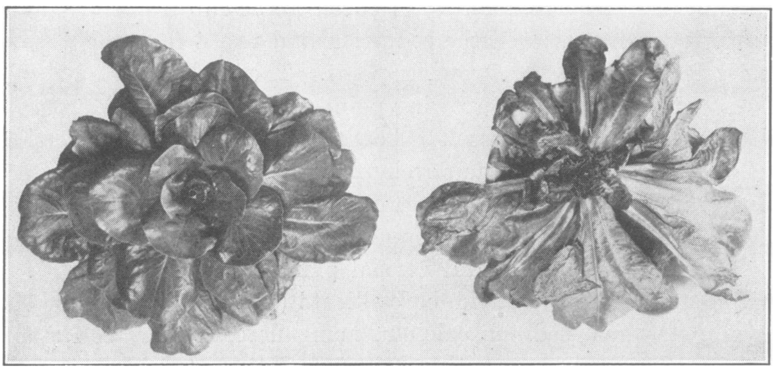

FIG. 6. Same plants as in figure 4, 6 weeks after addition of boric acid to the one on the left.

content by 0.1 p.p.m. from no boron to 1.5 p.p.m. The range between 1.5 and 3.0 p.p.m. was covered by increase of 0.3 p.p.m. boron.

Plants that did not receive boron showed injury shortly after being transferred to the experimental cultures. With 0.1 and 0.2 p.p.m. boron in the medium, plants made much slower growth than those receiving larger quantities, within non-toxic range. The presence of 0.3 p.p.m. boron in the nutrient solution enabled plants to make continued growth until shortly before reaching maturity; then during periods of rapid growth injury would appear on the more rapidly growing leaves. During periods of lower activity, imposed by shading or unfavorable weather conditions, growth would be resumed, with the production of apparently normal leaves. The plants of this group were much smaller than normal plants and did not produce flowers. All plants in the group grown in a boron concentration of 0.4 p.p.m. were free from leaf injury. Florescence occurred although

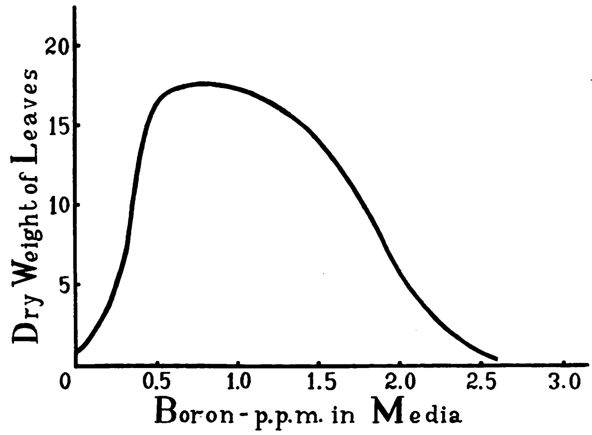

FIG. 7. Dry weight, in grams, of leaves of lettuce plants grown in the presence of different quantities of boric acid.

but few seeds were produced. Quantities of boron between 0.4 and 0.9 p.p.m. in the culture resulted in the production of vigorous, rapidly growing plants with no evidence of toxicity or boron deficiency. Seed pods containing normal seeds were especially numerous on plants grown in concentrations of 0.6 and 0.7 p.p.m. boron. Nine-tenths of a part of boron per million was slightly toxic to lettuce, resulting in perceptible chlorosis of the lower leaves in most plants. The chlorosis was more pronounced with 1.0 p.p.m. boron in the nutrient solution. Boron concentration of 1.2 p.p.m. was decidedly toxic, causing chlorosis and death of the older leaves and large, white, necrotic spots on the edges of mature living leaves. All concentrations of boron from 1.2 to 2.5 p.p.m. produced increasing toxicity, as shown by necrosis and a significant decrease in the size of the plants.

Quantities of boron exceeding 2.5 p.p.m. were fatal to the seedlings. The effects of different quantities of boron on the growth of lettuce as determined by dry weight of the leaves are shown in figure 7. On the basis of dry weight, the optimum concentration of boron in water cultures for the growth of lettuce is 0.7 p.p.m. added in the form of boric acid.

The utilization of various boron compounds by lettuce was investigated in sand cultures to determine the relative amounts that must be present for normal growth. The powdered borates were mixed with purified sand in porcelain dishes before placing in the containers. Other mineral nutrients were added in solution as required through the period of growth. Treatments and results are given in table I.

Additions of boric acid, or the relatively soluble borates of potassium, sodium, and calcium to sand in sufficiently small quantities to avoid toxic effects were insufficient for the later growth requirements of the plants, unless a large volume of medium was used. Normal plants could not be grown in sand cultures of 750 or 1500 gm. without further additions of soluble boron compounds during growth. Cultures of 5 kg. containing sufficient soluble boron compounds to produce normal plants were not toxic to plants started during the early summer, but were decidedly toxic to seedlings started during periods of more limited light intensity and shorter daily exposure. The quantity of soluble borate in cultures of 10 kg. was decreased to a content that was non-toxic to seedlings at any period of the year without the appearance of deficiency symptoms in later growth.

The inclusion of 0.0025 gm. of boron as manganese borate in sand cultures was sufficient for the growth to maturity of the lettuce plant. Relatively large quantities of manganese borate were not toxic to plants in cultures having reaction exceeding pH 6.6. Increase in the acidity of cultures resulted in high concentrations of manganese borate becoming toxic. Toxicity resulting from an excess of manganese borate was due to the boron ion. The addition to sand cultures of sufficient copper borate to supply the plants' boron requirements throughout the period of growth resulted in toxic concentrations of the copper ion.

Boro-silicate in the form of powdered Pyrex glass was found to be the most satisfactory source of boron for sand cultures. Quantities sufficient for the successive growth to maturity of several plants were included in the medium without toxicity or the development of deficiency symptoms. Slight changes in the reaction of the culture did not affect the solubility of the boro-silicate.

The ratio between the quantity of boron available and the quantity absorbed and its relation to the physical condition of the plants was ascertained by determining the boron content of plants grown in water cultures

TABLE I

EFFECTS OF DIFFERENT QUANTITIES OF BORON COMPOUNDS ON GROWTH OF LETTUCE

Compound	Boron per kg. sand	Effect of boron compound on plant
	gm.	
Boric acid	0.0005	Deficiency severe
	0.0010	Deficiency severe
	0.0015	Slightly toxic, final deficiency
	0.0020	Toxic
Potassium borate	0.0005	Deficiency severe
	0.0010	Deficiency severe
	0.0015	Deficiency; some toxicity
	0.0020	Toxic
Sodium borate	0.0005	Deficiency severe
	0.0010	Deficiency severe
	0.0015	Deficiency
	0.0020	Toxic
Calcium borate	0.0010	Deficiency severe
	0.0015	Deficiency
	0.0020	Slightly toxic at first; good growth
	0.0025	Toxic
Manganese borate	0.0025	Good growth
	0.0075	Very good growth; plant normal
	0.0100	Slightly toxic
	0.0150	Boron and manganese toxic
Copper borate	0.0010	Deficiency severe
	0.0025	Cu. slightly toxic
	0.0050	Cu. toxic; severe
	0.0075	Seedlings killed
Zinc borate	0.0010	Deficiency severe
	0.0050	No deficiency or toxicity
	0.0100	Zn. toxic, slight
	0.0150	Zn. toxic, severe
Boro-silicate (powdered Pyrex glass, 40 mesh)	10.0	Plant normal
	25.0	Plant normal
	50.00	Very slightly toxic
	100.00	Definitely toxic

at constant concentrations of boron. The boron content of normal lettuce varied between 25 and 50 p.p.m. boron of the moisture-free tissues. All plants containing less than 20 p.p.m. boron showed some degree of deficiency. Boron toxicity occurred in all plants containing more than 60 p.p.m. boron.

Figure 8 shows the effects of different concentrations of boric acid in

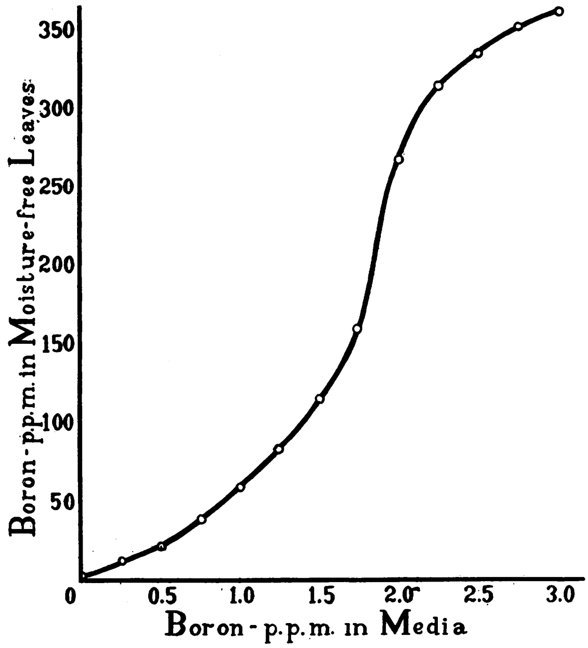

FIG. 8. Absorption of boron from nutrient solutions of different concentrations of boric acid.

the nutrient solution on the absorption of boron by lettuce. The concentration in the leaves depended upon the concentration of soluble boron in the solution. Slight increases in the boron content of a solution exceeding toxic concentrations resulted in large increases in the boron content of the leaves. Additions of boric acid greater than the quantity sufficient to kill the seedlings rapidly caused a slightly greater increase in the boron content of the leaves than did the minimum lethal concentration, indicating a relation between the concentration of boron in the medium and the rate of absorption by the plant.

Summary

1. A deficiency disease of lettuce resulting from an insufficiency of boron is described and illustrated.

2. The effectiveness of several boron compounds in preventing or correcting the deficiency disease is given.

3. The concentrations of soluble boron compounds that result in boron deficiency, normal growth, and toxicity were ascertained.

4. The physical condition of the plant was modified by the concentration of soluble boron in the nutritive solution.

5. The effect of the less soluble boron compounds was modified by the reaction of the culture, the volume, and, through the plant itself, by climatic and seasonal conditions affecting the rate of growth.

6. Boro-silicate was found to be the most satisfactory compound for incorporation in sand cultures.

7. Increase in the boron content of the nutrient solutions up to concentrations that rapidly resulted in the death of the seedlings produced increasingly greater concentrations of boron in the leaf tissue.

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