SOME EFFECTS OF BORAX UPON THE GROWTH, APPEARANCE AND CHEMICAL COMPOSITION OF CERTAIN PLANTS.

by

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INTRODUCTION

In the last decade the roles played in the development of plants by a number of elements occurring in them in small quantities have been undergoing rigorous investigation. The importance of several of these elements in plant growth has been universally admitted. Prominent among them is boron.

As far back as 1857, Wittstein and Apoiger (32) obtained from the ash of the seeds of a certain Abyssinian plant a crystalline substance answering to the test for boric acid. Since that time, with the help of improved methods of analysis, boron has been found to be present in the ash of most plants. The presence of boron in plants is not entirely accidental as small amounts are essential for proper development.

The exact role played by boron in plant nutrition is not yet definitely established. Many investigators, however, have shown that its absence results in an internal breakdown of the plant cells and finally death of the plant.

The general method for the study of the effects of a single element in plant growth involves the use of nutrient solutions. These solutions contain the salts of the essential nutrient elements -- nitrogen, phosphorus, sulphur, potassium, magnesium, calcium, iron and small quantities of the minor elements. Through the use of these solutions it soon became obvious that the quantity of boron necessary for normal growth varied with different plants. Moreover, the quantity of boron available to plants, a factor of great importance, has been shown to have no significant correlation with the amount of boron in the soil (6).

While the need of boron for plant growth has been receiving considerable attention, fewer investigators have been concerned with the specific effects of boron within the plant and its relationship to other elements. It is the purpose of this investigation to study the nature of boron fixation by the soil and to consider the effects of borax on the growth, appearance, and chemical composition of certain plants.

From the standpoint of fertilizers the form in which boron is most readily procurable and, at present, least costly is granulated borax ($Na_2B_4O_7 \cdot 10H_2O$). This compound contains 11.34 per cent boron.

LABORATORY PROCEDURES

Standard laboratory methods were used in the chemical analyses of plant tissue. All analyses were made on tissue dried in the oven at 65°C.

Boron was determined by the Berger-Truog method (1).

Calcium and magnesium were determined on the same ash samples; calcium by titrating the oxalate with standardized potassium permanganate and the magnesium by the gravimetric pyro-phosphate method.

Iron was determined by titrating the ferric ion with a dilute standardized titanium trichloride.

A modified Gunning procedure was used to determine nitrogen.

Potassium was determined by the chloro-platanic method.

I. SOIL FIXATION OF BORON

Type of Fixation

It has been reported that boron deficiency occurs more frequently in alkaline than in acid soils (4,14,15) and that over-liming may produce boron starvation (20,21).

Ferguson and Wright (11) have pointed out that the fixation of boron in the soil by lime may happen in one of three ways.

(1) "Lime may fix boron into some insoluble or slightly soluble form.

(2) "Lime increases the pH of the soil and thereby may reduce the ability of the root to absorb boron.

(3) "Lime may stimulate the growth of soil micro-organisms until there is competition between them and the plant for the supply of boron."

In a report by Cook and Millar (6) some factors affecting boron availability have been pointed out. The growth and appearance of soybean plants were used as a measure of the availability of boron, as these plants exhibit very plain and dependable symptoms of toxicity when a small excess of boron is present. It was assumed when borax is applied to soils in fairly heavy quantities and the soybean plant is not injured, that some constituents of the soil render the boron unavailable to the plant.

The boron toxicity symptoms of soybeans are first noticed about ten days after the plants emerge from the soil. Yellowish brown spots form near the edges of the leaves, as illustrated by Figure 1. The cotyledons turn yellow and drop

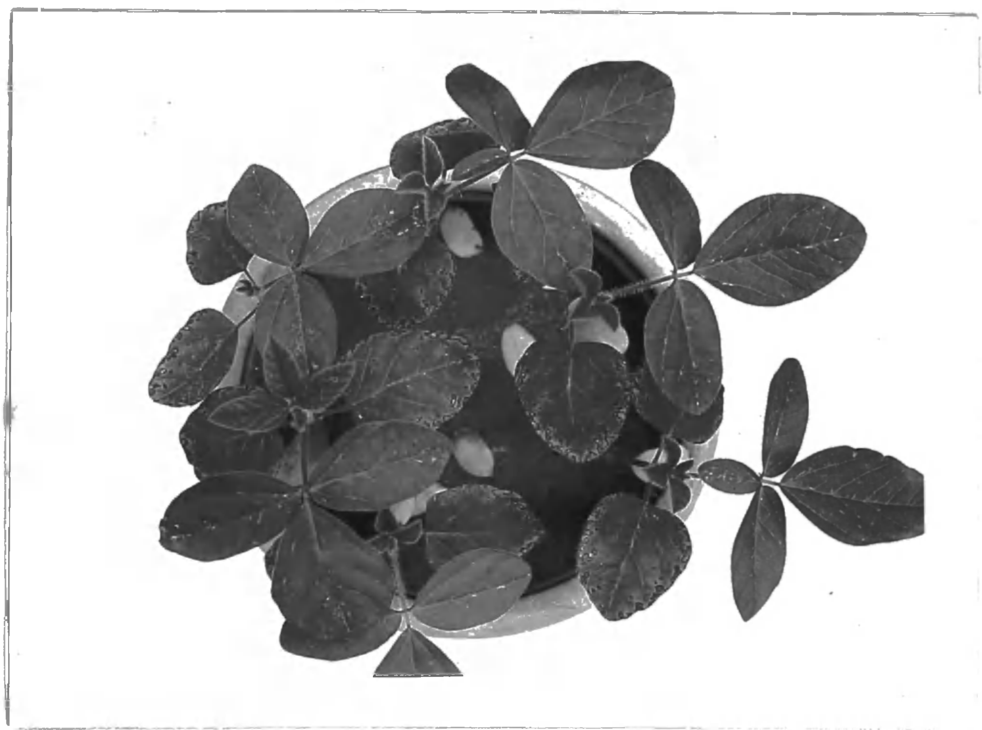

Figure 1. Soybeans showing yellowish brown spots near the edges of the leaves, characteristic of boron toxicity.

off earlier on the plants injured by borax. An excessive quantity of borax also causes a rapid development of new leaves at the top end of the stem and a premature death of the base leaves.

From the yield data (See Table 1.) taken from the above mentioned report, the following conclusions were drawn.

(1) "Calcium and magnesium carbonates were very effective in fixing borax into forms not available to soybeans. Sodium carbonate had no effect on the availability of borax.

(2) "Calcium and magnesium sulphates were partially effective on Hillsdale soil in fixing borax into forms not available to soybeans. They had no effect on Warsaw soil. Sodium sulphate had no effect on either soil."

The soybean plants whose yield data and toxicity symptoms made it possible to draw the above conclusions, were analyzed to study the relationship between plant composition and soil factors affecting boron fixation.

The plants from each replication were dried, ground to pass through a 1 mm. sieve and then combined to form composite samples.

The soybeans were grown on two soils: Hillsdale B horizon and Warsaw sandy loam. These soils were placed in 1-gallon glazed earthenware jars and soybeans were planted immediately after the application of the nutrients. The treatments are stated in terms of equivalents per acre.

Table 1. The effect of borax[1] upon the percentage decrease in yield and the boron, calcium, magnesium and nitrogen contents of soybeans grown upon variously treated pots of Hillsdale B horizon and Warsaw sandy loam soil types.

Soil Type	Soil treatment	Yield[2] decrease	Soil pH	Boron-ppm. N.B.[3]	Boron-ppm. B.[4]	%CaO N.B.	%CaO B.	%MgO N.B.	%MgO B.	%N N.B.	%N B.
		%									
Hillsdale	Check	20.7	4.60	27	90	1.49	1.68	1.28	1.32	1.66	2.06
B	4T $CaCO_3$	3.0	7.45	18	50	3.01	2.70	0.81	0.82	1.85	1.84
horizon	1T $CaSO_4$	14.3	4.65	28	77	1.77	1.94	1.06	1.22	1.65	2.51
	4T $MgCO_3$	5.7	7.60	18	57	0.46	0.47	2.71	2.61	3.30	3.42
	0.5T $MgSO_4$	8.8	5.00	30	75	0.95	1.29	1.50	1.55	1.92	2.10
	1T Na_2CO_3	29.5	6.25	30	100	1.45	1.59	1.16	1.23	2.56	3.02
	0.5T Na_2SO_4	20.3	4.95	30	95	1.29	1.48	1.14	1.07	2.16	2.66
Warsaw	Check	24.0	5.20	25	90	2.31	2.34	1.62	1.51	4.32	4.44
	4T $CaCO_3$	3.7	6.95	18	45	2.51	2.51	1.49	1.48	4.40	4.36
	2T $CaSO_4$	22.2	4.85	30	90	2.27	2.42	1.56	1.43	4.15	4.21
	4T $MgCO_3$	6.7	6.98	22	60	1.26	1.25	2.35	2.33	4.27	4.21
	1T $MgSO_4$	24.4	5.10	27	85	2.00	2.15	1.63	1.45	3.85	4.25
	1T Na_2CO_3	25.0	6.00	28	90	1.95	2.08	1.64	1.62	4.41	4.50
	1T Na_2SO_4	25.9	5.00	37	90	2.15	2.17	1.52	1.38	4.13	4.41

[1] 10 pounds per acre on Hillsdale loam, 20 pounds per acre on Warsaw sandy loam.
[2] Based on similar treatments not receiving borax.
[3] Boron had been omitted from the nutrient solution.
[4] Boron had been added to the nutrient solution.

On the Hillsdale B horizon the following were included, with and without borax at the rate of 10 pounds: $CaCO_3$, 4 tons; $CaSO_4$, 1 ton; $MgCO_3$, 4 tons; and Na_2SO_4, 5 tons. The Warsaw sandy loam soil received double the above rate of $CaSO_4$, $MgSO_4$, Na_2SO_4 and borax, and the same applications of $CaCO_3$, $Mg\ CO_3$ and Na_2CO_3.

<u>Boron</u> - As indicated in Table 1, the $CaCO_3$ and $MgCO_3$ lowered the plant intake of boron. Where no borax had been applied to Hillsdale B horizon the boron content of the dried plant tissue was lowered from 27 to 18 ppm. by both $CaCO_3$ and $MgCO_3$. Where borax had been applied the decrease in boron content as a result of the application of these liming materials was from 90 to 50 and 57 ppm., respectively. Similar changes were also observed in boron content of the plant tissue grown on Warsaw soil receiving applications of $CaCO_3$ and $MgCO_3$.

The boron content of the plants from cultures receiving the Na_2CO_3 and Na_2SO_4 treatments varied only slightly with respect to the check. Where borax had been applied to the check, Na_2SO_4 and Na_2CO_3 treated pots, the boron content of soybean plants increased from about 25 to 90 ppm. in both soil types, as compared with the plants not receiving borax.

The action of $MgSO_4$ and $CaSO_4$ with respect to the boron content of the soybean plant is not consistent in the two soil types. Neither treatment had any influence on either soil type with respect to the boron content of the plant where borax had not been applied. Where borax was applied to the pots of Hillsdale B horizon soil, the plants contained less boron than did those from the same treatment on the check pots. $CaSO_4$ and $MgSO_4$ treatments in comparison with the check pots lowered the boron content of the dry plant tissue from 90 to 77 and 75 ppm., respectively. The plants grown on similar treatments in the Warsaw soil showed only slight deviations from the check.

The data in Table 1 also indicate that wherever boron caused a decrease in yield the boron content of the plant tissue increased substantially. Treatments which entirely or partially prevented borax from decreasing the yield also decreased the boron content of the plant tissue.

Calcium - Toxic quantities of boron seemed to have very little influence on the content of calcium in the plant tissue. However, those plants which were injured by borax contained slightly more calcium than normal ones. Plants from treatments which showed no decrease in yield by the application of borax showed no significant change in calcium content.

While the observation has no connection with borax, it is interesting to note, especially with respect to the plants grown on Hillsdale soil, that calcium and magnesium contents of the tissue were considerably higher where their respective carbonates were used, over where their respective sulphates were used. This seems to fit in nicely with Jenny's (16) idea of contact feeding. Although greater concentrations of the carbonates were used the solubilities of the sulphates are considerably higher.

Magnesium - In general the magnesium content of the soybean was not altered by an injurious application of borax.

Nitrogen - As shown in Table 1, there was an increase in nitrogen content in the tissue of those plants injured by boron, grown on the Hillsdale B horizon. Little change was found in any of the plants grown on the Warsaw soil.

Discussion - In general plants injured by borax were higher in boron, calcium and nitrogen content than normal ones. These differences were much more apparent in tissue of the plants grown on the Hillsdale B horizon than those grown on the Warsaw soil. The soil factors which prevented boron toxicity symptoms and reduction in yield are correlated with low boron content within the plant tissue. This is further proof that the boron was changed to a form not available to the soybean plant.

In an article (7) recently presented for publication, of which the writer is co-author, three factors were found to influence the fixation of boron. These are active calcium[1], organic matter and clay content of the soil. These factors were determined by growing soybeans in nine different Michigan soils. These soils were selected because of their wide variation in texture, reaction and organic matter content.

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[1] "Active calcium was determined by leaching 10 gms. of soil with acidified ammonium acitate. The calcium thus determined was that in the exchangeable form and as carbonates."

The treatments on each soil type included borax at the rates of 0, 10 and 20 pounds per acre. All treatments were replicated three times. Adequate quantities of all nutrient elements, with the exception of boron, were applied to each pot. Ten soybean seeds were planted in each pot and the seedlings thinned to six plants shortly after they emerged from the soil. The effect of borax on the growth and appearance of the soybeans varied with the soil type. For example, plants grown on Thomas sandy loam soil made a greater growth as a result of both the 10 and 20 pound applications of borax, while the soybeans grown on the Fox sandy loam were seriously injured by the 10 pound application. In order to understand what constituents of the soil cause boron to become unavailable in one soil and not in another, several soils were analyzed. No single soil constituent seemed to correlate with the relative yields[2]. From the data it soon became evident that several soil constituents played a role in preventing applied borax from proving toxic to soybeans, and in order to explain why borax proved toxic on one soil and beneficial on another it was necessary to consider the relative quantities in the soil of all three constituents - active calcium, organic matter and clay. In order to group all three soil constituents into one factor which would be indicative of the response of soybeans to applied borax, relative amounts of each constituent were determined. For example, since Thomas soil has the greatest organic matter content - 14.01 per cent -

[2]Based on the yield from the soil without borax - as 100.00.

its relative organic matter factor is 100.00. Warsaw soil, containing 4.65 per cent organic matter has a relative factor of 33.19 or 33.19 per cent as much organic matter as the Thomas soil. Likewise, for each of the soil constituents, as indicated in Table 2, a relative figure was determined.

A soil factor was determined for each individual soil by averaging the relative amounts of the three soil constituents. This soil factor gives a very good index as to how soybeans would respond to greenhouse applications of borax. For each application of borax the relative yields on the nine soils and the corresponding soil factors give a very high correlation ($r = 0.967$ for the 10 pound application and $r = 0.974$ for the 20 pound application.). The conclusion drawn from this work is stated as follows. "Inverse and very high correlations were found to exist between the availability of boron, applied as borax, to soybeans and the active calcium organic matter and clay contents of nine soils. From such correlations it was possible to construct lines of best fit which may be used for soybeans grown in pot cultures of an unknown soil. The prediction thus may be useful in making recommendations regarding the field use of borax on that particular soil."

Soybeans grown in the above experiment were dried, composited, ground to pass through a 1 mm. sieve and analyzed. The results of the analyses are found in Table 2.

Table 2. The relationship between soil factors, yields and the chemical analyses of the soybean tissue from plants grown on nine different Michigan soils, as affected by borax applications.

	Relative yields[1]		Soil Constituents-relative amounts				Boron-ppm.			%CaO			$\%Fe_2O_3$			%N		
	10#	20#	Active Ca. m.e./100g.	Organic matter	Clay	Soil[2] factor	N.B.	10#B	20#B	N.B.	10#B	20#B	N.B.	10#B	20#B	N.B.	10#B	20#B
Fox	58.3	33.3	1.54	11.49	26.70	13.24	60	--	150*	1.71	--	1.85*	.059	--	.054*	3.38	--	4.24*
Berrien	73.0	58.3	4.07	16.85	13.35	11.42	30	65	110	1.76	1.98	2.10	.033	.037	.020	2.20	3.10	3.32
Hillsdale	87.1	72.9	18.83	29.34	48.54	32.73	30	50	80	2.12	2.32	2.25	.020	.021	.017	2.69	2.80	3.04
Warsaw	88.9	69.4	9.04	33.19	46.60	29.61	30	60	100	2.10	2.06	2.22	.042	.036	.034	3.05	3.20	3.63
Miami	96.6	87.9	15.91	28.55	63.59	36.02	25	50	80	2.09	2.07	2.17	.030	.026	.024	3.19	3.18	3.22
Wisner	101.2	100.0	46.37	55.96	49.03	50.45	25	36	55	2.53	2.72	2.52	.049	.037	.037	2.68	2.73	2.71
Macomb	112.0	98.3	25.59	56.10	77.67	53.12	36	45	65	2.11	2.12	2.22	.042	.105	.062	3.15	2.92	3.12
Brookston	120.0	117.8	38.61	62.88	100.00	67.17	23	45	70	2.22	2.58	2.56	.024	.030	.026	3.36	3.32	3.33
Thomas	125.0	132.3	100.00	100.00	26.20	75.40	15	25	30	2.25	2.22	2.18	.029	.031	.031	3.41	3.32	3.37

[1] Stated as a percentage of yield obtained on soils not treated with borax.
[2] Obtained by averaging the relative values for the three soil constituents.
*Composite of plants grown on pots receiving 10 and 20 pound applications of borax.

Boron - The boron content of the soybean tissue was markedly increased through the application of borax. However, the rate of increase, the content of the boron in soybean plants grown on the various soil types and the responses in yield varied considerably with the soil type. The Thomas soil, having a pH of 7.5 and an organic matter content of 14.01 per cent, grew soybeans which were the lowest in boron content. This soil, while showing the greatest response to borax in yield, failed to show a great increase of boron in the tissue.

The Fox soil which was very acid and low in organic matter content grew plants which were high in boron and with the application of borax the amount in the tissue increased from 60 to 150 ppm.

In general the plants grown on soils which have a high soil factor were lower in boron content than those plants which were grown on soils with a low soil factor. The amount of boron in the plant tissue was directly influenced by the soil conditions which prevented toxicity symptoms and reduction of yields.

A definite correlation can be noted between response of the soybeans to borax and the amount of boron in the plant tissue. When the boron content of the plant tissue, on the dry basis, reached approximately 30 ppm. yields were not further increased. The toxic range was not reached until the plant tissue contained between 50 and 60 ppm. of boron.

Calcium - The calcium content of the soybean plant was influenced slightly by borax applications. There is a tendency for higher calcium content in those plants which were injured by borax. This is especially apparent in the soybeans grown on Berrien soil. The calcium content of soybeans grown on this soil was increased from 1.76 to 2.10 per cent by an application of 20 pounds per acre. In contrast, the soybeans grown on Thomas soil seemed slightly lower in calcium content although the calcium content was not markedly altered by the borax.

Iron - According to the data, borax did not affect the iron content of the soybean plant.

Nitrogen - As indicated in Table 2, the nitrogen content of the soybean tissue apparently was not altered by the boron content until the amount of boron in the plant tissue reached the toxic quantity. For example, the plants from the Berrien soil were increased from 2.20 to 3.10 in per cent of nitrogen by an application of borax equivalent to 10 pounds per acre. This change was accompanied by a decrease in yield from 11.5 to 8.4 gms. per pot. However, the plants grown on the Wisner soil showed no signs of toxicity and no reduction in yield from borax. The nitrogen content of the dry tissue of the plants grown on this soil did not vary with borax treatments.

Naftel (21) has reported that boron fixation by overliming is due to the stimulation of growth of soil microorganisms resulting in the available boron being largely used in building the bodies of the organisms. Midgley and Dunklee (20) on the other hand report that the fixation is chemical rather than biological.

As a means of obtaining further information on the idea of fixation through cell metabolism an experiment was set up to determine whether a stimulation of soil micro-organisms by means other than lime would decrease the available boron in the soil.

Soybeans were grown in 1-gallon glazed earthenware jars each filled with 5 kgms. of Warsaw sandy loam soil. This soil, with a pH of 6.0, is not too acid for bacterial development but is sufficiently acid so that added lime fixes applied borax. Four soil treatments in sets of six included a check and applications of $CaCO_3$, equivalent to 8 tons per acre, $CaSO_4$ equivalent to 4 tons per acre, and sucrose equivalent to 18 tons per acre. To three of each set of six pots borax was applied at the rate of 20 pounds per acre. Adequate quantities of nutrient elements, with the exception of boron, were applied to all pots.

Ten seeds were planted in each pot and the seedlings were thinned to six plants shortly after they had emerged from the soil. The moisture content was kept uniform by frequent additions of distilled water.

<u>Results</u>. The results of this experiment are shown in Table 3. It will be noted that sucrose failed to reduce the toxic effects of boron as the yields on pots

receiving borax were decreased 17.4 per cent. This is practically the same decrease in yield as was caused by borax in the check pots.

Table 3. The effects of $CaCO_3$, $CaSO_4$ and sucrose on the fixation of boron as indicated by yields of the entire soybean plants, grown in Warsaw sandy loam pot cultures.

Treatment	Degree of toxicity and percentage decrease in yield as a result of applying borax* after the treatment indicated.	
	Toxicity	Yield decrease
		%
None	Very serious	19.4
$CaCO_3$, 8 tons	None	0.0
$CaSO_4$, 4 tons	Medium	9.4
Sucrose, 18 tons	Very serious	17.4

*Equivalent to 20 pounds per acre.

The $CaSO_4$ reduced the toxicity of borax and this evidence tends to verify the conclusions drawn from the data in Table 1.

No toxicity symptoms or other harmful effects were apparent on the plants grown in the limed pots receiving borax. This observation is supported by the fact that the yield was not altered in comparison with that of similarly limed pots not receiving borax.

As the presumably increased number of organisms caused by the addition of sugar to the culture did not change the applied boron into some form not injurious to soybeans, it seems logical to assume that the role of lime is not simply that of stimulating the micro-organisms but that it plays another altogether different role in fixing boron into an unavailable form.

From the data given it appears that the causes of boron fixation in the soil are quite complex. First, $CaCO_3$ rendered the boron unavailable and nontoxic to soybeans but Na_2CO_3 failed to prevent boron from being toxic, making it appear that fixation was not influenced a great deal by pH. However, $CaSO_4$ only partially reduced the toxic effects of borax indicating that fixation was not entirely due to the calcium ion. As the fixation of boron appeared not to be biological in nature, it became apparent that pH must have some indirect effect upon this tie-up. In order to confirm this idea an experiment was set up to attack the question from a different angle. It was thought that if pH has any influence on the unavailability of boron in an alkaline soil some treatment which would lower the pH should make the soil boron more available to the plant. With this idea in view the following investigation was made.

Sugar beets were grown in 2-gallon glazed earthenware jars filled with 8 kgms. of Thomas sandy loam soil taken from the area shown in Figure 2. This soil has a pH of 7.5 and contains free carbonates. It has repeatedly shown responses to borax treatments in greenhouse cultures.

By laboratory experiments the amount of sulphur necessary to lower the pH from 7.5 to 6.2 was determined to be approximately six and one-half tons per acre. Sulphur was thoroughly mixed at this rate into the soil of four of a series

Figure 2. An area of Thomas sandy loam soil near Unionville, where practically all the beets showed heart rot symptoms.

of eight pots. To two of each set of four pots borax was applied at a rate equivalent to ten pounds per acre. All other nutrient elements were applied in adequate quantities.

Four sugar beet plants were transplanted into each pot soon after they had emerged from the quartz sand in which the seeds were germinated. The moisture content of all the pots was kept uniform by frequent additions of distilled water.

<u>Results</u> - As shown by the data reported in Table 4, all plants grown in cultures without boron or sulphur were affected with heart rot, while all plants receiving either boron or sulphur produced healthy plants. In the

Table 4. The effect of sulphur and borax on heart rot occurrence and the yield of sugar beets grown on Thomas sandy loam pot cultures.

Treatment		Plants showing heart rot	pH	Green Wt. per pot*	
Base	Nutrients			Roots	Tops
		%		gms.	gms.
Control	Without boron	100	8.0	24.7	65.2
	With boron	0	8.0	35.1	125.3
Sulphur	Without boron	0	6.2	34.7	130.4
	With boron	0	6.2	37.5	164.0

* Average of two replications.

series not treated with sulphur, boron applied as borax at the rate of ten pounds per acre increased the yield of roots from 24.7 to 35.1 gms. per pot, and the yield of tops from 65.2 to 125.3 gms. per pot. In a like manner, sulphur applied at the rate of six and one-half tons per acre and without borax increased the yield of roots from 24.7 to 34.7 gms. per pot and the yield of tops from 65.2 to 130.4 gms. per pot. Thus the effect of the application of sulphur in lowering the pH from 7.5 to 6.2 must have liberated boron to the extent that the yield was increased in comparison with that obtained from the application of ten pounds of borax.

The application of both sulphur and boron had no advantage over either boron or sulphur alone. The yield of tops of the plants grown in the sulphur pots was increased from 130.4 to 164.0 gms. per pot by an addition of borax, although the root increase was only 34.7 to 37.5 gms. per pot, the latter figures being entirely within experimental error.

Such data would indicate that pH does play a major role in the fixation of boron, but, as indicated by the yield data in Table 1, pH is not the only factor influencing the availability of boron. As far as lime is concerned in the fixation of this element, its effects really are two fold. First, it raises the pH of the soil and secondly furnishes the calcium ion, both of which seem essential in fixing boron into an unavailable form.

Rate of Fixation

A number of investigators (2,3,26,34) have reported that toxicity of boron on sensitive plants has been lessened considerably by delaying the planting date several weeks after application of the borax. Two reasons for this have been suggested.

(1) Some of the readily soluble borax has been leached out of the immediate reach of the young plants.

(2) A large portion of the borax has been changed over to some less soluble form and therefore is less available to the plant.

An experiment was started late in the fall of 1939 to determine the fixing capacity of Thomas sandy loam soil for boron. The usual procedure for the application of nutrients to pot cultures had been carried out but as the length of day was very short it was considered advisable to wait until the following spring to plant the soybeans. Accordingly, the pots were covered with wax paper and the date of planting postponed for approximately six months. The treatments included applications of borax at the rates of 0, 20, 40, 80 and 100 pounds per acre.

In the spring ten seeds were planted in each 1-gallon pot and the seedlings thinned to six soon after emerging from the soil. Their growth was observed and the length of time necessary for the appearance of toxicity symptoms noted.

Little or no indication of toxicity was noticed on the soybean plants until about 20 days after the plants had emerged from the soil. At this time a few symptoms were apparent on the plants which received the 100 pound application of borax. The remainder of the plants, as indicated in Table 5,

Table 5. The effect of borax on the yield of the entire plant and the toxicity of soybeans grown on Thomas sandy loam pot cultures planted six months after application.

Treatment	Yield per pot*	Toxicity
	gms.	
Check	11.3	None
20# Borax	10.3	"
40# "	11.1	"
80# "	9.8	"
100# "	8.4	Slight

*Yields are averages of two replicates.

did show a slight depression in yield.

The data in Table 5 seemed rather strange since symptoms of toxicity had been observed when 20 pounds of borax had been applied on the same soil in an earlier experiment. Therefore a new series of pots was set up to see how much injury to soybeans might occur on the same soil when the soybeans were planted immediately after the borax applications were made.

In a new series soybeans were again grown in 1-gallon glazed earthenware jars filled with 4 kgms. of the Thomas sandy loam soil. The usual applications of nutrient elements with the exception of boron were applied to the soil. The duplicated treatments included 0, 10, 20, 50 and 100 pound applications of borax. Immediately after the application of the nutrients, the usual procedure of planting was followed. The plants were thinned to an even stand and their growth and appearance noted and recorded.

A few days after the removal of the first crop of soybeans, the soil in each pot was removed, remixed and replaced in the pot. A second crop of soybeans was planted on the soil approximately two months after the application of the borax. An even stand in the pots was again maintained and the effects of borax noted.

As shown in Table 6, the plants seeded immediately after the application of borax showed marked signs of toxicity. About ten days after emerging from the soil, the toxicity symptoms were first observed. The pots with the heavy applications of borax showed the first symptoms, which soon became very marked and the plants made a spindling growth and almost died. The yields from pots which received more than 20 pounds of borax per acre were greatly decreased while those from the pots which received 10 pound applications were slightly increased, from 26.5 to 28.1 gms. per pot. The 100

Table 6. The effect of various quantities of borax and the time of planting, on the toxicity of soybeans grown in Thomas sandy loam pot cultures.

Treatment	First Crop[2]		Second Crop[3]	
	Yield[1]	Toxicity	Yield[1]	Toxicity
	gms.		gms.	
Check	26.5	None	15.2	None
10# Borax	28.1	"	15.8	"
20# "	23.5	Slight	16.3	"
50# "	9.1	Serious	8.9	Slight
100# "	4.5	Very serious	7.2	Serious

[1]Yields are averages of two replicates.
[2]Planted immediately after applications of borax.
[3]Planted two months after the application of borax.

pound application caused a decrease in yield from 26.5 to 4.5 gms. per pot. The trend in yields decreased inversely as the rate of application increased from 10 to 100 pounds.

The second crop of soybeans failed, as indicated in Table 6, to show any toxicity signs on the pots receiving borax at the rates of 10 and 20 pounds per acre. The yields of the soybeans receiving these applications were slightly above those of the check pots. The soybeans that received borax at the rates of 50 and 100 pounds per acre showed toxicity signs and reduction in yields. In neither case, however, were the toxicity symptoms or reductions in yield nearly so severe as in the first crop. The 100 pound application reduced the yield 83 per cent for the first crop and only 52 per cent for the second.

These experiments, while not quite identical in set-up, indicate very clearly that the fixation of boron on the soil studied is not instantaneous but a rather slow process.

II. SYMPTOMS OF BORON STARVATION AND THE EFFECT OF BORAX ON THE YIELD AND CHEMICAL COMPOSITION OF SEVERAL CROPS

Plant symptoms have been used for a long time to indicate the lack or over-supply of certain nutrient elements within the soil. While it is impossible to distinguish all plant needs by certain characteristic starvation or toxicity symptoms no one denies their value in solving plant nutrition problems. This is especially true in case of the minor elements, since the quantities of these elements compose such a small fraction of the soil and the quantity necessary for normal plant growth is so extremely small. Furthermore, chemical analyses may fail to differentiate between the available and non-available forms of the minor elements and for that reason may not always give an accurate indication of the response plants may make to an application of the minor elements under consideration. A study of plant symptoms followed by soil and plant analyses should give the most accurate insight into the individual requirements of soils for proper plant development.

In order to determine what characteristic symptoms are correlated with boron starvation and to secure plants for analysis, a number of plants were grown in greenhouse cultures. These were also supplemented in a few cases with plants from field plots. Certain plants which showed definite boron starvation symptoms were analyzed. All these analyses were made to see if any correlation exists between the quantity of certain elements in the plant and the starvation symptoms.

Methods for greenhouse studies pertaining to Part II of this thesis have very much in common. To avoid repetition, the general greenhouse experimental procedure may be summarized as follows. The crops were grown in glazed earthenware jars filled with either Thomas sandy loam or quartz sand. Adequate quantities of all nutrient elements with the exception of boron were supplied in all cases. These quantities -- per 1-gallon jar and per acre -- are stated in Table 7.

Table 7. The quantity of each nutrient element applied to greenhouse pot cultures and its equivalent in pounds per acre.

Nutrient	Gms. per gal. pot	lbs./ acre	Nutrient	Gms. per gal. pot	lbs./ acre
[1]$FePO_4$	1.00	500.0	$MnSO_4 \cdot 4H_2O$	0.008	4.0
[1]$CaHPO_4 \cdot 2H_2O$	0.50	250.0	$CuSO_4$	0.005	2.5
KNO_3	0.50	250.0	$NaCl$	0.005	2.5
$Ca(NO_3)_2 \cdot 4H_2O$	0.25	125.0	$ZnSO_4$	0.005	2.5
$MgSO_4 \cdot 7H_2O$	0.25	125.0	NaI	0.001	0.5
$Al_2(SO_4)_3 \cdot H_2O$	0.0125	6.3	[2]$Ca(HPO_4)_2$	0.144	72.0

[1]Applied separately as dry salt to sand culture.
[2]Applied separately in solution to Thomas sandy loam pot cultures.

Uniform moisture relationships were maintained in all jars by frequent weighing and addition of distilled water.

The number of plants within the jars was kept uniform for each individual crop by early thinning or by direct transplanting. The quantity of borax applied varied with the crop under study.

At harvest time the plants were dried in an oven at 65°C. and ground to pass through a 1 mm. sieve.

Insufficient tissue in many cases limited the number of analyses that could be made.

Symptoms of Boron Starvation

Sugar Beets - The boron starvation symptoms of the beets have been reported in an earlier article (4) as follows. "Leaf symptoms are first noticed. These are illustrated by the plants in the greenhouse pot cultures as shown in Figure 3.

Figure 3. A large number of small leaves some twisted and abnormally shaped, indicate boron starvation.

The blackened and checked petioles are positive signs of the heart rot. Shortened and twisted petioles and large numbers of small leaves are also reliable signs.

"An insufficient supply of boron results in a breakdown of the tissue in certain portions of the plant. In the sugar beet the death of the growing center of the crown and the production of such beets as shown in Figure 4 have resulted in the name heart rot. Later in the season

Figure 4. After the fall rains start, new leaves often come out from around the dead heart. These leaves may soon die or may attain full growth, according to the condition of the beet.

some beets send out a large number of leaves from around the edge of the crown. These leaves may die after reaching the stage shown in Figure 4, or they may continue to grow until harvest time when they practically cover the dead heart.

"All sugar beets suffering from an insufficient supply of boron do not exhibit the same symptoms of deficiency. Some show leaf symptoms only, while others suffer breakdown of the root tissue."

<u>Canning Beets</u>.- Red beets grown on boron deficient soils show definite starvation symptoms. These symptoms have been described in several previous articles (5,17,22,29).

The outstanding signs of boron deficiency in red beets occur within the root and has been termed "internal black spot" (30). These spots are irregular in shape and usually occur near the surface but occa~~s~~sionally in the central portion of the beet. The breakdown is generally found in the lower portion, but in extreme cases it may extend throughout the beet. The spots are dark in color and corky in texture. The spots are not altered greatly by cooking and present an unsightly appearance in the sliced beets. Beet roots of boron deficient plants are usually rather flattened in shape and less symetrical than are the normal beets.

In general the leaf symptoms are similar to those observed in sugar beets. The leaves are distorted and twisted; one side of the leaf develops faster than the other, giving the appearance of a half-spiral. The concave side of the petiole displays a characteristic cross-checked appearance.

The affected leaves die and drop off early, while new leaves continue to develop from the center of the crown. In extreme cases the beet takes on a rosette appearance, with numerous small leaves around the crown.

While the deep, unusually red color of the leaves of red beets is not always indicative of boron starvation, it is found in association with the above symptoms.

Mangels - Boron deficiency symptoms of mangels are very similar to those of sugar beets. The checking of the petioles is not quite so prominent in mangels as in sugar beets, but the shortened, twisted and deformed leaves are very common and numerous small leaves appear at the lower edges of the crown. The new leaves are generally at right angles to the crown and give the plant a flattened appearance.

The roots in the pot cultures all showed internal breakdown of the tissue as illustrated in Figure 5. Cankers

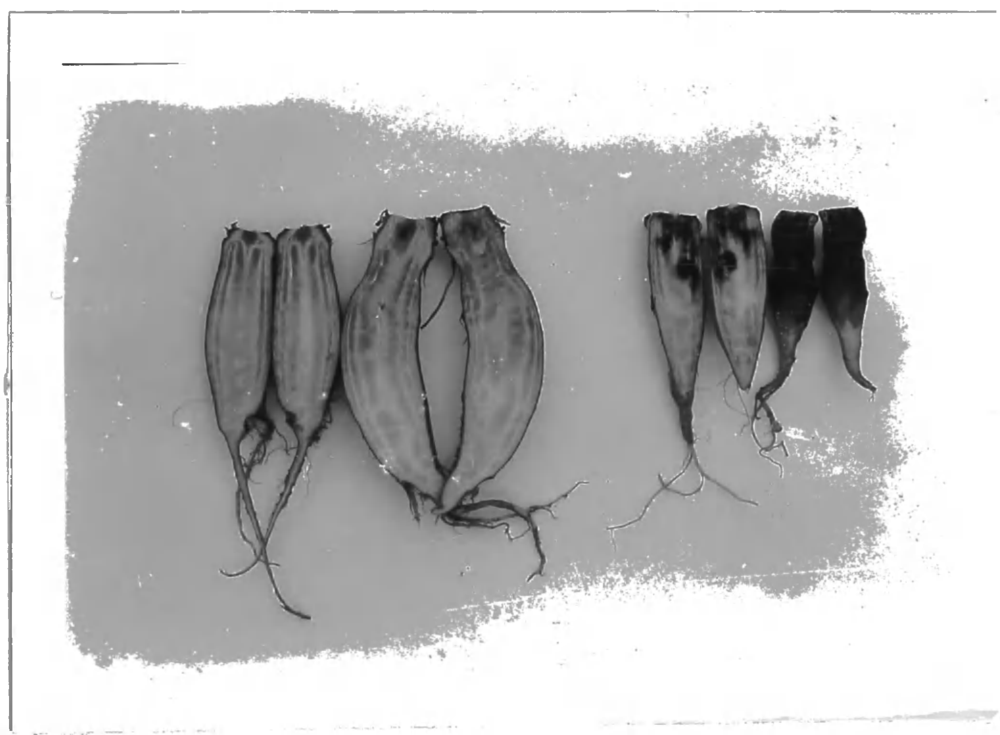

Figure 5. The effect of borax on the growth and quality of mangel roots grown in sand cultures.
Left - 2.5 pounds of borax per acre.
Right - No borax.

have also been noticed in roots from fields where top symptoms have indicated boron deficiency.

<u>Rutabagas</u> - The leaf symptoms of rutabagas are less marked than are those of the sugar beet. Some of the leaves die prematurely but there are fewer deformed leaves than are found on either sugar beets or mangels.

The most pronounced symptoms are found in the root. As is true in most cases of boron deficiency in root crops there is an internal breakdown of the tissue. Instead of cankers, however, the root develops a "water-core" or "brown-heart" condition which appears as dark brown water-soaked areas in the central portion of the root. These areas may vary from small spots to areas comprising most of the interior portion of the root.

<u>Turnips</u> - Other than growth, little difference as a result of boron application could be noted in the tops of the turnips. The roots of the plants growing in soil to which no borax had been applied were less elongated than were the normal plants. Only a few small spots indicated a condition similar to that reported as "brown-heart". McLeod (19) reports that "brown-heart" is not usually found until the root exceeds 2 inches in diameter. This probably explains why the turnips grown in the greenhouse failed to develop this condition. Coulson and Raymond (8) described the external symptoms as roughened skin on the roots and the development of yellowish, mottled and distorted leaves. Davis and

Ferguson (9) report the internal symptoms of the root with "brown-heart" as a darkened, water-soaked condition of the tissue which may develop into a hollow center.

<u>Radishes</u> - No leaf or root symptoms of boron starvation other than size could be noted in the radishes grown on pot cultures. However, Wolf (33) reports checking of the petioles, a condition similar to sugar beets, and Truniger (27) found that radishes grown on pot cultures without borax had characteristic woody cankers on the sides of the roots.

<u>Chicory</u> - When starved for born this plant made only a stunted growth. Many of the leaves were twisted and the petioles and midribs of the leaves were weakened. As a result of this condition some of the leaves were broken and those not broken failed to stand as erect as did the leaves of normal plants. A very pronounced reddening occurred in the leaves of boron starved plants.

The roots of the normal plant, as indicated in Figure 6, were much larger and contained a more fibrous root system. No internal break-down of the tissue could be noticed in any of the roots.

<u>Barley</u> - The barley plants showed very little difference in growth until the plants started to head, except for a slightly heavier growth in the borax treated pots. The time of heading, as indicated in Figure 7, was hastened about ten days by the borax application. The pots receiving the heavier application headed first and those receiving

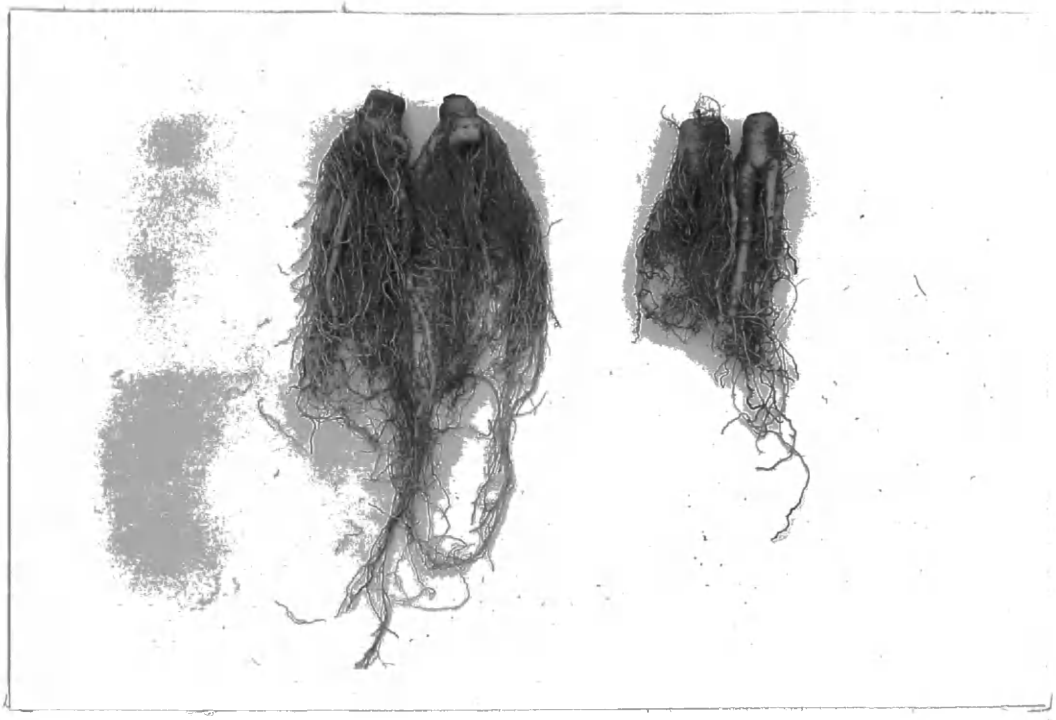

Figure 6. The effect of borax on the browth of chicory roots in sand cultures.
Left - 3.5 pounds of borax per acre.
Right - No borax.

Figure 7. The effect of borax on the growth of barley in Thomas sandy loam pot cultures.
Left - No borax. Center - 2.5 pounds of borax per acre. Right - 5 pounds of borax per acre. Note the difference in the heading.

the lighter application followed in order. Some of the plants in the untreated pots failed to produce heads and some plants which did produce heads were stunted and little grain was formed.

Wheat - The only noticeable effect of the borax upon the growth of the wheat was the time of heading. The wheat in the pots receiving borax headed a few days sooner than those plants not receiving borax.

Corn - No early effects of borax on the growth of corn were noticed. However, when the tassels started to shoot, the leaves of the plants grown in pots without borax were tinged with red. The normal plants were larger, as illustrated in Figure 8, and failed to show to any degree the red color in the leaves.

The deficient plants were slower in tasseling than the normal ones. The symptoms of streaking of the leaves as reported by van Overbeck (28) were not noticed in these plants.

Dandelions - Dandelions were transplanted from the college campus into pots filled with Thomas sandy loam soil. Three plants were placed in each pot. Treatments, a check and borax at the rate of 5 pounds per acre, were each replicated four times.

The plants receiving borax made a more luxuriant growth and the leaves stood more erect than was the case with plants starved for boron. As indicated in Figure 9, borax influenced the blossoming and seed development of the

Figure 8. The effect of borax on the growth of corn in Thomas sandy loam pot cultures.

Left - No borax.
Center - 5 pounds of borax per acre.
Right - 10 pounds of borax per acre.

Figure 9. The effect of borax on the blooming of dandelions in Thomas sandy loam pot cultures.

Left - No borax.
Right - 5 pounds of borax per acre.

plants. Shortly after transplanting some of the plants in the borax treated pots started to bloom. While the time of blooming of these plants was not uniform every plant receiving borax blossomed quite profusely. In contrast, not one of the twelve plants without borax blossomed.

The Effect of Borax on Yields and the Chemical Composition of Several Crops.

Numerous investigators (4,8,9,19) have reported increased yields of sugar beets, mangels, turnips and rutabagas as a result of applications of borax. Cook and Millar (4) have reported higher percentages of sugar in normal sugar beets than in those suffering from heart rot. Improved quality of canning beets, cabbage, cauliflower and celery has been reported (5,29, 10,11,23) to be the result of applications of borax on soils deficient in this element.

Some writers (12,31) have reported better growth and larger yields of alfalfa and clover as a result of borax applied in pots and in the field but it seems that plants belonging to the family graminaceae need very little boron and do not respond readily to applications of borax.

Various explanations have been advanced for the physiological breakdown in the tissue of many plants suffering from boron starvation. Schmidt (24) has advanced the opinion, based on experimental data, that plants suffering from insufficient boron assimilate more nitrate nitrogen than is needed and that the cells break down as a result of the high nitrate concentration. It has also been mentioned that the function of boron is to act as a regulator of the permeability of the plasma membrane in controlling the intake of certain ions.

To furnish more information on the response of various crops to borax and to throw more light on the relationship which may exist between the intake of boron and other elements into the plant the following pages are devoted to a report of the yields of crops grown for the purpose of studying plant symptoms. Attention is also given to the effect of borax, applied to the soil, on the content of boron, iron, nitrogen, potassium, calcium, and magnesium in the dried plant tissue.

SUGAR BEETS

Sugar beets were grown in pot cultures of Thomas sandy loam soil. Various elements were separately omitted from some nutrient solutions supplied to the cultures and doubled in concentration in others. Borax was supplied at rates of 10 and 20 pounds per acre, respectively. The effect of the borax on growth was determined by weighing the roots and tops at harvest time. The samples were saved for chemical analyses.

To supplement the analyses made on plants grown in greenhouse cultures, field samples from the same soil type were analyzed. These were gathered according to the appearance or non-appearance of heart rot symptoms. The beets with heart rot were selected from the area shown in Figure 1, and the normal beets from another area in the same field.

Yields

In the Thomas sandy loam pot cultures borax, applied at the rate of 10 pounds per acre, prevented heart rot and increased the yield of roots from 46.7 to 90.4 gms. per pot and the yield of tops from 109.0 to 131.4 gms. per pot. The 20 pound application of borax resulted in a slightly greater yield of tops but a smaller yield of roots than was obtained as a result of the 10 pound treatment.

Composition

The effect of boron starvation on the composition of both the tops and roots of sugar beet plants is shown by the data reported in Tables 8 and 9.

Boron - The boron content of the dried tops of the beets grown in pot cultures was increased from 10 to 20 ppm. by the 10 pound application of borax and from 10 to 24 ppm. by the 20 pound application. Likewise the roots from the plants which had received borax contained more boron. The increase in boron content was from 10 to 14 and 15 ppm. for the 10 and 20 pound applications, respectively.

The data obtained from the analyses made on field samples show close resemblance to those obtained from the greenhouse sample analyses. The boron content of the dry tissue of field grown beets having heart rot was 10 ppm., identical with that of similar beets produced in pot cultures. The dried tissue of normal beets produced in the field contained 16 ppm. of boron as compared to 15 ppm. in the dried tissue of beets grown in pot cultures which had received borax.

Iron - The iron content of both roots and tops of the sugar beets grown in the green house pot cultures was considerably higher in the plants which were low in boron content. The iron content of the dried roots was decreased from .023 to .013 per cent by a borax application equivalent to 10 pounds per acre.

Marked differences were found in the iron content of field grown beets. That of the dried tissue from beets showing symptoms of heart rot was .028 per cent as compared to .011 per cent in the tissue of normal beets.

Table 8. The effect of borax on the yield and mineral analyses of sugar beets grown in Thomas sandy loam pot cultures.

Treat-ment	Yield*		Boron ppm.		Iron %		K_2O %	Nitrogen %		Magnesium%		Calcium%	
	Roots	Tops	Tops	Roots	Tops	Roots	Roots	Tops	Roots	Tops	Roots	Tops	Roots
0#B.	46.7	109.0	10	10	.129	.023	.90	2.29	.90	1.95	.57	1.80	.47
10#B.	90.4	131.4	20	14	.098	.013	.91	1.63	.76	1.74	.53	1.60	.44
20#B.	81.7	136.6	24.	15	.106	.014	.91	1.62	.75	1.75	.55	1.80	.42

*Average of six replications

Table 9. The effect of apparent boron starvation on the mineral content of sugar beet roots grown on Thomas sandy loam soil.

	Boron/ ppm.	Iron %	K_2O %	Nitrogen %	Magnesium %	Calcium %
Boron deficient	10	.028	1.21	2.16	.96	.34
Normal	16	.011	1.33	1.54	.68	.23

<u>Potassium</u> - Field grown sugar beets with heart rot were lower in potassium than were normal beets. These results vary from those obtained from greenhouse cultures in which there was no apparent change in the potassium content as a result of the application of borax.

<u>Nitrogen</u> - Boron starvation in the plant was accompanied by a higher content of nitrogen in both the roots and the tops. In the pot cultures an application of borax at the rate of 10 pounds per acre decreased the content of nitrogen by .14 per cent in the dried roots and by .66 per cent in the dried tops. The doubled application of borax did not cause a further decrease in the nitrogen content of the dry tissue.

In the field samples the beets showing heart rot symptoms contained .62 per cent more nitrogen in the dried tissue than did the normal ones. The percentage of nitrogen in the field samples was higher than in the pot-culture samples.

<u>Calcium and Magnesium</u> - The 10 pound application of borax produced only slight changes in the calcium and magnesium contents of the sugar beet plants grown in pot cultures. The data indicate, however, a general trend toward higher percentages of these elements in plants grown in a medium containing an insufficient supply of boron. This trend is quite evident in the samples obtained from the field.

CANNING BEETS

Canning beets, otherwise spoken of as "garden beets", were grown in Thomas sandy loam pot cultures. Three pots received complete nutrient solution including borax at the rate of 10 pounds per acre and three others received nutrient solution from which the borax had been omitted. The effect of borax was determined from the weight of the roots and tops at the end of 65 days from the date of planting and from analyses made on the dried tissue of the roots and tops.

The effect of borax applied in the field on this crop was determined from random samples selected from plats included in an experiment conducted on Emmet sandy loam by Cook and Millar (5). The samples were selected from eight plats on two different farms. Four of the eight plats received borax applied broadcast at the rate of 40 pounds per acre and the other four received no borax. The percentages of beets in the random samples showing signs of boron starvation, internal black soot, were determined by slicing the samples.

Yields and Black Spot Occurrence

As shown by the data presented in Table 10 the growth of the garden beet in pot cultures was greatly stimulated by

Table 10. The effect of borax on the yield of canning beets and on the boron and nitrogen content of canning beet tops grown in pot cultures of Thomas sandy loam soil.

Treatment	*Yield /pot Roots	Tops	Boron	Nitrogen
			ppm.	%
0# Borax	2.5	7.9	7.5	1.78
10# Borax	7.3	14.9	27.5	1.45

* Average of three replications.

the application of borax. The yield of roots was increased from 2.5 to 7.3 gms. and that of the tops from 7.9 to 14.9 gms. per pot by a 10 pound application. Borax applied in the field at the rate of 40 pounds per acre was very effective in reducing signs of boron starvation. The data reported in Table 11 show that this reduction was from 54.30 to 5.96 per cent.

Table 11. The effect of borax on the occurrence of internal black spot and the boron and nitrogen content of canning beets grown in Antrim county.

Treatment	Beets showing* internal black spot	Boron ppm.	Nitrogen %
0# Boron	54.30	17.3	2.01
40# Boron	5.96	19.9	2.02

*Average of four plots.

Composition

Boron - The boron content of the dried tops of canning beets grown in Thomas sandy loam pot cultures was increased from 7.5 to 27.5 ppm. by an application of 10 pounds of borax per acre. Considering the low level of boron in the tissue of the untreated plants the increase seems highly significant.

Applied in the field on Emmet sandy loam an application of borax at the rate of 40 pounds per acre increased the boron content of the dry tissue from 17.3 to 18.9 per cent. This difference is slight compared to that obtained in the beets grown in pot cultures. The difference in results obtained in the two experiments may be the result of leaching which occurred in the field.

Nitrogen - The nitrogen content of the dried tissue of beets grown in pot cultures was lowered from 1.78 to 1.45 per cent by an application of 10 pounds per acre of borax. No differences occurred in the nitrogen contents of beets grown in the field experiments.

MANGELS

Mangels were grown in sand cultures with and without borax. The rate of borax application was equivalent to 2.5 pounds per acre. The treatments were replicated four times.

Yields

As indicated in Table 12 borax applied to mangels grown in sand cultures at the rate of 2.5 pounds per acre increased the yield of tops from 4.2 to 8.7 gms. and of roots from 7.8 to 22.6 gms. per pot.

Table 12. The effect of borax on the yield and boron, nitrogen and iron content of sugar beets grown in sand cultures.

Treatment	*Yield/pot Roots	*Yield/pot Tops	Boron ppm. Roots	Boron ppm. Tops	Nitrogen % Roots	Nitrogen % Tops	Iron % Roots	Iron % Tops
0# Borax	7.8	4.2	7.5	17.5	1.36	1.53	.014	.035
2.5# Borax	22.6	8.7	10.0	50.0	1.02	1.35	.011	.029

*Average of four replications.

Composition

Boron - The boron content of the dry top tissue was increased from 17.5 to 50.0 ppm. and that of the dry root tissue from 7.5 to 10.0 ppm.

Nitrogen - In the dry tissue of the mangel, nitrogen was decreased from 1.63 to 1.35 per cent in the tops and from 1.36 to 1.02 per cent in the roots.

Iron - The iron content of the dry mangel tissue decreased from .035 to .029 per cent in the tops and from .014 to .011 per cent in the roots with an application of 2.5 pounds per acre of borax.

RUTABAGAS

Field samples of rutabagas were selected according to boron deficiency symptoms from a Brookston clay loam soil located near Ionia, Michigan. Normal plants and those showing symptoms of boron starvation, brown heart, were selected from the same field.

Composition

Boron - As indicated in Table 13, the normal rutabaga plants were higher in boron than were the deficient ones. The dried tops of normal plants contained 10 ppm. more of boron than did the deficient tops and the dry root tissue from normal plants contained 5 ppm. more than did roots with brown heart.

Table 13. A partial analysis of normal and boron deficient rutabagas grown on Brookston clay loam.

Symptoms	Boron ppm.		Nitrogen %		Iron %	
	Roots	Tops	Roots	Tops	Roots	Tops
Normal	15	30	2.15	2.19	.036	.228
Boron deficient	10	20	2.23	2.43	.078	.499

Nitrogen - The nitrogen content of the normal plants was lower than that of those starved for boron. The difference on the dry basis was .08 per cent in the case of the roots and .24 per cent in the tops.

Iron - The iron content of the rutabagas showing brown heart was more than double that of the normal plants. The dried tops from the infected roots contained .497 per cent iron while the dried tops from normal roots contained only .228 per cent of iron. The roots contained less iron than the tops, but the same relationship between iron content and the deficiency symptoms held.

The results of these analyses show rather conclusively that the symptoms present in the rutabaga roots were really those of boron starvation.

TURNIPS

Turnips were grown in Thomas sandy loam pot cultures. Treatments consisted of a check and borax equivalent to 5 pounds per acre. Treatments were replicated two times.

Yields

As indicated in Table 14 an application of borax, equivalent to 5 pounds per acre increased the yield of both the tops and the roots of turnips grown on Thomas sandy loam pot cultures. The yield of roots was increased from 44.2 to 49.2 gms. per pot and the yield of tops from 54.7 to 66.0 gms. per pot.

Table 14. The effect of borax on the yield of turnips grown on Thomas sandy loam pot cultures.

Treatment	*Yield	
	Roots	Tops
	gms.	gms.
0# Borax	44.2	54.7
5# Borax	49.2	66.0

*Average of two replicates.

RADISHES

Radishes were grown in Thomas sandy loam pot cultures. Treatments consisted of a check and borax applied at the rate of 5 pounds per acre. Each treatment was replicated two times.

Yields

The effect of borax on the yield of radishes is indicated in Table 15. An application equivalent to 5 pounds of borax per acre caused the yield of radish roots to increase from 31.5 to 53.9 gms. per pot. A small increase in the yield of tops accompanied the increase in yield of roots.

Table 15. The effect of borax upon the yield and partial analysis of radishes grown on Thomas sandy loam pot cultures.

Treatment	*Yield gms. Roots:Tops		Boron ppm. Roots:Tops		Nitrogen % Roots:Tops		Iron % Roots:Tops	
0# Borax	53.9	31.5	17.5	20.0	2.88	4.25	.064	.032
5# Borax	57.7	53.9	20.0	37.0	2.52	4.08	.043	.023

*Average of two replicates.

Composition

<u>Boron</u> - As indicated in Table 15, the borax treated plants were higher in boron content than were those not treated with the salt. The boron content of the dried root tissue was raised 2.5 ppm. and that of the tops 17.0 ppm. by this small application.

<u>Nitrogen</u> - The nitrogen content of both the tops and roots of radishes was decreased by borax. This decrease in the dried tissue of the roots was .36 per cent and in the dried top tissue it was .21 per cent.

<u>Iron</u> - The iron content of the radishes not receiving borax was higher than that of those receiving borax. The percentage of iron in the dried tops and roots was decreased from .032 to .023 per cent and .064 and .043 per cent, respectively, by an application of borax equivalent to five pounds per acre.

CHICORY

Chicory was grown in quartz sand cultures. The treatments consisted of a check and an application of borax at the rate of 3.5 pounds per acre. All treatments were replicated four times.

Yields

An application of borax at the rate of 3.5 pounds per acre increased the yield of chicory roots from 29.5 to 32.4 gms. and the yield of tops from 15.6 to 19.6 gms. per pot. The data are reported in Table 16.

Table 16. The effect of borax on the yield and analysis of chicory grown in sand cultures.

Treatment	*Yield gms. Roots	*Yield gms. Tops	Boron ppm. Roots	Boron ppm. Tops	Nitrogen % Roots	Nitrogen % Tops	K_2O % Roots	Iron % Roots
0# Borax	24.9	15.6	7	14	0.34	1.15	1.32	.014
3.5# Borax	32.4	19.6	9	28	0.24	1.07	1.17	.011

* Average of four replicates.

Boron - The borax increased the boron content of the dried chicory roots only slightly but doubled the boron content of the dried leaves. The increase was from 14. to 28. ppm.

Nitrogen - The nitrogen content of the roots and tops of the chicory plant was decreased by the borax application. The decrease in the nitrogen content of the dried roots was from .34 to .24 per cent and that of the tops was from 1.15 to 1.07 per cent.

Potassium and Iron - The potassium and iron contents of the chicory roots were likewise decreased by the 3.5 pound application of borax. On the dry basis this increase amounted to .15 per cent for potassium and .003 per cent for iron.

BARLEY

Barley was planted on Thomas sandy loam soil and borax was applied at the rates of 2.5 and 5.0 pounds per acre. Each treatment was replicated three times.

Yields

The effect of borax on the yield of the entire barley plant is shown in Table 17. Applications of borax equivalent to 2.5 and 5.0 pounds per acre, respectively, increased the yield of barley from 3.2 to 4.6 and 4.9 gms. per pot.

Table 17. The effect of borax on the total yield of the barley plant grown in Thomas sandy loam pot cultures.

Treatment	Total yield of plant*
	gms.
0# Borax	3.2
2.5# Borax	4.6
5.0# Borax	4.9

*Average of three replicates.

WHEAT

Winter wheat was planted in the fall in Thomas sandy loam pot cultures. The jars were left in a screened room, without glass and adjacent to the greenhouse, until mid-winter when they were moved into the greenhouse. The treatments consisted of borax at the rates 0, 2.5 and 5.0 pounds per acre, replicated three times.

Yields

The borax resulted in slightly increased yields as shown by the data reported in Table 18. The pots receiving borax at the rate of 2.5 pounds per acre yielded 2.0 gms. per pot more than did those which received borax at the rate of 5 pounds per acre. The 5 pound per acre application may have been too much for the crop. That the small increase in yield recorded for the 2.5 pound per acre application of borax is not entirely due to experimental error is indicated by the fact that the wheat which received borax headed before that grown without borax.

Table 18. The effect of borax on the yield of the entire wheat plant grown in Thomas sandy loam pot cultures.

Treatment	Yield * gms. per pot
0# Borax	18.8
2.5# Borax	20.8
5.0# Borax	19.3

* Average of three replications.

CORN

Corn was grown in 2-gallon jars filled with 8 kgms. of Thomas soil. Borax was applied at the rates of 5 and 10 pounds per acre. The treatments were replicated three times.

Yields

As indicated in Table 19, borax applied at the rates of 5 and 10 pounds per acre increased the yield of the total corn plants from 86.5 to 103.5 and 117.4 gms. per pot, respectively.

Composition

Boron - The boron content of the dried corn plants, roots and tops, was increased from 5 to 15 ppm. by an application of 5 pounds of borax per acre and from 5 to 18 ppm. by an application of 10 pounds per acre.

Nitrogen - The nitrogen content of the corn was not altered by applications of borax.

<u>Iron</u> - The iron content of the dried tissue of the corn plant was decreased from .052 to .045 per cent by an application of borax equivalent to 5 pounds per acre. An additional 5 pounds of borax did not further decrease the iron content of the dried tissue.

Table 19. The effect of borax on the yield* and partial analysis* of corn grown on Thomas sandy loam pot cultures.

Treatment	Yield of Fodder gms.	Boron ppm.	Nitrogen %	Iron %
0# Borax	86.5	5	1.20	.052
5# Borax	103.5	15	1.26	.045
10# Borax	117.4	18	1.18	.046

*Average of three replications.

DISCUSSION

As the data in the preceeding sections indicate, most plants that are deprived of boron, accumulate larger quantities of calcium, nitrogen, magnesium, and iron. The greatest differences in mineral content between the normal and deficient plants occur in the contents of iron, nitrogen, and boron. Borax applied to boron deficient soils reduces the nitrogen and calcium content of plants grown thereon provided there is an increase in yield, but when toxic quantities of borax reduce the yields the calcium and nitrogen contents of the plants are often greater than those of the deficient plants. Several investigators (12,13,24,25) have reported higher nitrogen contents on a number of crops over similar crops receiving sufficient boron. Few investigations have been reported concerning the iron-boron relationship.

The accumulation of calcium in boron deficient plants has been reported by Shkolnik (25). Some evidence has been presented which indicates that deficient plants are low in potassium. However, the data reported in this paper leads one to believe that potassium content is not greatly altered by response of plants to boron. Field grown sugar beets showing boron deficiency symptoms were low in potassium, while chicory roots growing in boron deficient greenhouse cultures were high in this element. In no case was there a large difference in potassium content as a result of applications of borax.

Application of borax resulted in an increase in the boron content of the tissue of all plants. It was found also that field samples of sugar beets, canning beets and rutabagas showing boron deficiency symptoms contained less boron than did normal crops grown in the same fields.

The data might lead one to believe that the function of boron is to act as a regulator of the permeability of the plasma membrane and control the intake of certain ions. However, the increased quantities of nitrogen, iron, and calcium in deficient plants, may be entirely due to retarded plant development. The data regarding potassium, however, tend to disprove the latter idea.

Boron appears to have definite functions within the plant. Root cells of the sugar beet, canning beet, rutabaga, turnip and radish developed improperly and formed woody cankers or "brown heart" if not supplied with a small quantity of boron. The premature death of old leaves and the development of numerous small leaves usually accompanies the development of woody tissue in the root crops.

Cereals and other seed-bearing plants often fail to blossom and develop fruit with insufficient supply of boron. Lohnis (18) reports that wheat, rye, and barley failed to produce fertile blossoms without small quantities of boron. A decrease in the blossoming of snap dragons has been reported to be due to the lack of boron (12). Improper development of cotton buds has also been related to boron deficiency (26).

In the experiments reported here, corn, wheat, barley and dandelions failed to develop seeds properly when boron was lacking.

There is little doubt that different plants require different amounts of boron for proper growth. The amount required for wheat would hardly be sufficient for sugar beets. It appears also that some plants may be far superior in their ability to secure boron from the soil. Soybeans, sensitive to moderate applications of borax, require more boron in the tissue on the dry basis than do sugar beets. The dry tissue of various crops grown on Thomas sandy loam pot cultures varied in boron from 5 to 20 ppm. where borax had not been applied. Applications of borax which may prove toxic for one crop may hardly be sufficient for another.

SUMMARY AND CONCLUSIONS

Soybeans were grown in pot cultures of Warsaw sandy loam and Hillsdale B. horizon. The soil treatments consisted of $CaCO_3$, $CaSO_4$, $MgCO_3$, $MgSO_4$, Na_2CO_3, Na_2SO_4 and a control with and without borax. These soybeans were analyzed by the author for boron, calcium and nitrogen to determine the effects of these treatments on the chemical composition of the plant.

Soybeans were grown in pot cultures of nine Michigan soils. Soil treatments included borax at rates equivalent to 0, 10 and 20 pounds per acre. These were grown to determine the soil factors influencing boron fixation. The analyses of the soybean plants from these pot cultures were made to determine the influence of soil factors and the application of borax on the content of boron, calcium, magnesium, iron, and nitrogen in the plant tissue.

To ascertain the effect of pH on the availability of boron, sugar beets were grown on an alkaline soil. This soil previously failed to supply sufficient boron for the proper development of sugar beets. Four treatments consisted of a check, borax equivalent to 10 pounds per acre, sulphur sufficient to lower the pH from 7.5 to 6.2 and sulphur with borax.

In order to determine the rate of fixation, soybeans were planted on Thomas soil at intervals of six months, two months and immediately after the application of borax at rates varying from 0 to 100 pounds per acre.

A number of crops - sugar beets, canning beets, mangels, rutabagas, turnips, radishes, chicory, barley, wheat, corn and dandelions - were grown on either a boron deficient soil or a boron deficient quartz sand culture. These crops were grown to determine boron deficiency symptoms and to secure normal and boron-deficient plant tissue for chemical analyses. Certain crops were analyzed for boron, calcium, nitrogen, potassium, magnesium and iron to see if any correlation exists between the mineral content of these crops and the supply of available boron in the soil.

The results of these experiments may be summarized as follows:

1. $CaCO_3$ and $MgCO_3$ applied to Warsaw and Hillsdale B horizon reduced the boron content of the soybean tissue.
2. Na_2CO_3 and Na_2SO_4 applied to the above soils did not alter the boron content of the soybean tissue.
3. $CaSO_4$ and $MgSO_4$ decreased the boron content of soybeans grown on the Hillsdale B horizon where excessive borax had been applied but did not alter the boron content of the tissue where borax had not been applied.
4. Accumulations of calcium and nitrogen accompanied an excessive boron content in the plant tissue.
5. The soil constituents, namely active calcium, organic matter and clay content, which prevent applied borax from becoming toxic to soybeans prevent boron from accumulating in the plant tissue.
6. Yields were increased with applications of borax until the boron content of the plant tissue, on the dry basis, reached 30 ppm.
7. Boron becomes toxic to soybeans when the content of the dry tissue exceeds 50 to 60 ppm.
8. The magnesium and iron contents of soybean tissue were not greatly altered by toxic quantities of boron.

9. Sulphur equivalent to six and one-half tons per acre, applied to Thomas sandy loam pot cultures, was as effective as borax in controlling heart rot of sugar beets.

10. Delayed planting in Thomas sandy loam pot cultures, after the application of toxic quantities of borax, reduced the toxic effect of the borax to soybeans.

11. An insufficient supply of boron for root crops is usually evidenced by breakdown in root tissue, distortion and premature death of the leaves and the forming of numerous small leaves.

12. Lack of sufficient amounts of boron for barley, wheat and corn delayed heading.

13. Dandelions with an insufficient supply of boron failed to bloom.

14. The tissue of plants deprived of boron was in most cases higher in percentage of calcium, nitrogen, magnesium and iron than was the tissue of plants grown in the presence of sufficient boron.

15. Borax applied to the soil in all cases increased the boron content of the dried tissue of plants grown on the soil.

16. Plants with characteristic boron deficiency symptoms were relatively low in boron content.

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