BORON IN RELATION TO GROWTH AND COMPOSITION OF TABLE BEETS (BETA VULGARIS L.)

by

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TABLE OF CONTENTS

BORON IN RELATION TO GROWTH AND COMPOSITION OF TABLE BEETS (BETA VULGARIS L.)

INTRODUCTION

The improved method of producing commercial fertilizers relatively free from impurities which previously often contained small amounts of various minor elements has served to aggravate deficiencies of these elements. It is generally accepted that organic manures contain small amounts of boron, manganese, copper, and other "trace" nutrients, and during the past few years the use of these manures has greatly decreased due to mechanized farming and increased application of commercial fertilizers, all of which may contribute to the occurrence of deficiency symptoms. When a soil is lacking in boron, various physiological disorders or nutritional disturbances may appear in the plants, thereby inducing characteristic deficiency symptoms.

Canker of table beets in Oregon was recognized, photographed, and described by Bouquet in 1933, and greenhouse experiments were made by Powers in 1937 to determine the cause of the trouble. As a result of these investigations, which showed, perhaps for the first time, that applications of borax would correct the canker, good commercial control was secured in the field the following year.

Losses are still recurring, however, and the purpose of this study was to learn further details of the relation of boron to the composition and quality of beets.

Identification of Beet Canker

Beet canker, or blackheart, upon which this study has been centered, appears as a dark spot on the root, usually on the part of the greatest circumference of the beet. Some roots may be very slightly affected with but one small spot of one-half to one inch in size, while other roots may have several spots to a degree where most of the root is blackened. Sometimes the canker or blackening may not be visible in the surface, but when the beet is sectioned the pithy areas are plainly seen extending into the fleshy part of the root from depths varying from one-eighth to one-quarter of an inch. As affected roots increase in size, the black spots frequently develop into growth cracks and large open cankers which may become infected or extend, in extreme cases, into a complete girdle of the root. The spots generally survive the canning process unless removed by hand and present an unsightly appearance in the sliced beets.

Leaf Symptoms

Leaf symptoms are often the best means of detecting the disease in the field. There is a fairly close correlation between the top symptoms and internal black spot. The youngest leaves and terminal buds show malnutrition symptoms first. They are distorted, often one-sided, and are commonly longer than normal leaves. The affected leaves die early and drop off, while new leaves develop the same symptoms and finally die. In extreme cases the result is a rosette appearance with the tips of the small leaves dying back.

Previous Work

Interest in boron in agriculture may be grouped by Naftel (1938) into six periods from the time of the discovery of this element in seeds by Wittstein and Apoiger (1837) to the present. (1) From 1836 to 1900, in which only eighteen papers were reported and the period was marked chiefly by the detection of boron in plants. (2) From 1900 to 1915 is the most important period since it includes the discovery of the essential nature of boron by Maze (1914). (3) From 1915 to 1925 marked a notable period when much interest was shown in this country. During the World War, American potash salts were first used on a large scale and it was soon discovered that toxic amounts of borax were being added along with the potassium. The chemist soon overcame this difficulty by removing the borax from the potash salts, but, even so, boron in this country received unfavorable interest and recognition of the true value of the element was delayed several years. (4) From 1925 to 1930 further proof of the necessity of boron in normal plant growth was obtained but interest was not as great as that shown in injury during the preceding period. (5) Interest suddenly rose in the next period, 1930 to 1936, when there were approximately 100 papers reported on boron, most of which were stimulated by the work of Brandenburg (1931), who reported that heart rot of sugar beets was caused by boron deficiency rather than by an organism. (6) The present period, beginning in 1936, may be characterized by the recognition of the fertilizer value of boron and a multitude of papers have been written on various phases of boron in relation to plant nutrition.

Agulhon (1910) reported that small amounts of boron had a beneficial effect upon the growth of higher plants, an observation later corroborated by the work of Brenchley (1914), Sommer and Sorokin (1928), Haas (1929), and others. Brandenburg's discovery (1931) that the heart rot of sugar beets, which was becoming prevalentin certain

German fields, was due to a deficiency of boron in the soil was soon confirmed by workers in several other countries.

Small applications of borax or boric acid have proved to be highly beneficial in areas where no plant symptoms of the trouble have been observed. Areas of limited deficiency are probably large and of greater economic importance than are areas where the deficiency has become so acute as to produce definite symptoms of malnutrition in plants.

Perhaps the first reference to the effect of boron on table beets was made by Boas (1934) when he showed that borates and boric acid lessened the deleterious effect of drought. Raleigh and Raymond (1937) found that soils treated with borax produced fewer beets affected with internal breakdown and those showing symptoms were only slightly injured. An attempt to correlate available boron in soils with canker of table beets was made by Berger and Truog (1939). They learned that beets grown in a soil low in available boron contained only 14.5 p.p.m. of boron, while beets grown on the same soil fertilized with boron contained 24 p.p.m. of that element. The amount of available boron in soils was discovered to be rather well correlated with the incidence of blackheart in red beets. As a result of water culture experiments, Tokuoka and

Morooka (1939) concluded that 0.01 p.p.m. of boron gave the maximum yield and increase and that 5.0 p.p.m. markedly decreased the yield.

Beets fertilized with 20 pounds of borax per acre were as free from canker and blackheart as those treated with 80 pounds of borax, according to Bouquet (1940). Purvis and Hanna (1940) found that table beets had deficiency symptoms with 30 pounds of borax per acre but that the extent of the injury was much less than in the untreated plots. Working with a sandy loam soil, Cook and Millar (1940) recommended that 10 to 30 pounds of borax per acre be applied to control the canker of table beets. Hornburg and Truog (1940) ran fertilizer trials which gave a 30 per cent increase in beet yield when 40 pounds of borax per acre were used alone and nearly eliminated blackheart. Borax with a complete fertilizer raised the yields to 66 per cent over the check plots. Truog (1940) reported that if boron is needed on beets, it should be applied at the rate of 30 to 50 pounds in borax per acre and not in direct contact with the seed. Boron deficiency in certain Wisconsin soils, according to Walker (1940), is the cause of black spot in table beets. The injury is worse after a drought followed by wet weather with rapid growth but can usually be corrected by the addition to the soil of 50 pounds of borax per acre.

Experiments in New York by Raleigh, Lorenz, and Sayre (1941) indicate that 50 pounds of borax per acre will give commercial control of canker. Harmer (1941) recommended that 25 pounds of borax per acre should be applied on acid mucks and 100 pounds per acre on alkaline mucks to prevent the incidence of canker.

A review of literature fails to reveal definite evidence of the optimum or critical concentration of boron for different conditions. Observations indicate a difference in susceptibility of different strains of beets to canker. Seasonal and moisture conditions are also found to need further study. The value of leaf and plant analyses and the boron content of normal beets have not been fully investigated.

EXPERIMENTAL

Description of Soils

The soils used to grow beets were Newberg, Chehalis, Amity, and Lake Labish peat.

The Newberg series is recent alluvial soil and has a brown surface and yellow-brown subsoil with a friable profile. It is a first-bottom soil laid down in swift water, giving it coarser subsoil. The reaction is approximately pH 6.0.

The Chehalis series is also a recent alluvial soil but represents the second-bottom soil laid down in backwater and has a less youthful profile with heavier subsoil. The pH is around 5.8 and the color is brown on finer, mellow yellow-brown subsoil.

The Amity series falls in the old valley fill group having poor or impeded drainage and a mottled subsoil. The pH is about 5.6 and the color is gray-brown on drab mottled subsoil.

The Lake Labish peat is well-decomposed willow sedge peat with a pH of 5.5 and nearly black color. It is 60 to 90 per cent organic matter.

Analytical Procedure

The fresh plant samples were dried at 60° to 70° C. and were ground in a Wiley mill to pass through a 100-mesh sieve, after which representative aliquots were taken for analysis.

The method used to analyze the plant material was the colorimetric one of Berger and Truog (1940) using quinalizarin as the color developer and comparing the unknown samples with prepared standards. The reaction depends on the fact that the addition of boron to quinalizarin (1, 2, 5, 8-tetrahydroxyanthroquinone) in concentrated sulfuric acid will cause a color change which can be used for the determination of boron. Fluorides, nitrates, dichromates, and other oxidizing compounds interfere with the test by turning the solution colorless and must, therefore, be removed before adding the quinalizarin.

Greenhouse Experiments

In the Fall of 1940, an experiment was started to determine the susceptibility of three different strains of Detroit dark red beets to applications of borax, using Newberg, Chehalis, and Amity soils. The strains tested were Ferry-Morse, Waldo Rohnert, and Associated. The rates of borax applied varied from 0-120 pounds per acre, in increments of 30 pounds. A complete fertilizer was applied to all the soils to insure that major elements would not be limiting factors.

The beets were allowed to grow five months and were then harvested, green weights of the roots and leaves taken, and the plants dried and ground for analysis. The results are found in Tables 1, 2, and 3.

A second trial was started in the late fall of 1941 and was harvested in April, 1942. The soils used were Willamette silt loam and Newberg sandy loam and the beets were Detroit dark red, Ferry-Morse strain. The rates of borax were the same as above and a complete fertilizer was also applied. The yield data are found in Table 4 as green weight of the roots and leaves.

Table 1

Insofar as yields and rates of application are concerned, the addition of borax gave increases over the untreated plots but there is little or no agreement between the amount applied and the yield. In no case did the highest rate of borax give the greatest growth and in two instances it actually depressed the yield beneath that of the check jars.

The Waldo Rohnert strain of Detroit dark red beets had slightly heavier growth than the other two,

Table 1. Yield of Table Beets
From Greenhouse Trials, 1941

Soil	Strain of Beets	Yield: Treatment in pounds per acre — Check	Borax 30	Borax 60	Borax 90	Borax 120
		grams	grams	grams	grams	grams
Newberg sandy loam	Ferry-Morse	8.04	7.90	6.67	10.66	6.95
	Waldo Rohnert	7.50	11.40	9.59	7.45	6.84
	Associated	6.95	10.04	9.05	7.67	8.82
Chehalis silt loam	Ferry-Morse	7.65	12.04	19.10	11.37	12.04
Amity silty clay loam	Ferry-Morse	13.37	19.06	17.00	23.64	16.66

but the increase is hardly significant and does not allow the drawing of any conclusions.

Table 2

Analyses of the soils used in this experiment show that the Amity has the largest amount of available boron in the original state, followed by Chehalis and Newberg. This agrees with the field observation that the Chehalis and Newberg are likely to be deficient in boron sonner than the old valley fill soils.

Addition of varying amounts of borax increased the available boron content progressively in all cases but not in any definite ratio. The 30-pound application raised the boron content markedly above that of the untreated soils, whereas the larger amounts of boron were not nearly so significant in their effect.

Table 3

Plant analyses failed to show any definite agreement between boron content of either roots or leaves and the applications of borax. The average boron in the borated plants was considerably higher than that found in the untreated plants but there were uneven fluctuations at the different levels of application and the correlation was not significant in most cases.

Table 2. Boron Content of Greenhouse Soils

Description of Sample	Rate per acre lbs.	Boron Content p.p.m.
Amity silty clay loam	untreated	0.60
	borax, 30	0.93
	borax, 60	1.08
	borax, 90	1.33
	borax. 120	1.43
Chehalis silt loam	untreated	0.48
	borax, 30	0.83
	borax, 60	0.98
	borax, 90	1.04
	borax, 120	1.19
Newberg sandy loam	untreated	0.43
	borax, 30	0.79
	borax, 60	0.95
	borax, 90	1.13
	borax, 120	1.28

Table 3. Boron Content of Table Beets From Greenhouse Trials

Soil and Strain of Beets	Treatment and Rate per acre	Boron Content	
		leaves	roots
	lbs.	p.p.m.	p.p.m.
Newberg sandy loam	untreated	53.0	19.0
Ferry-Morse	borax, 30	56.0	18.0
	borax, 60	59.0	22.0
	borax, 90	55.0	22.0
	borax, 120	56.6	25.0
Waldo Rohnert	untreated	58.0	16.6
	borax, 30	63.0	19.4
	borax, 60	63.0	19.0
	borax, 90	67.0	20.0
	borax, 120	66.0	19.4
Associated	untreated	57.0	17.0
	borax, 30	56.0	20.0
	borax, 60	64.0	17.4
	borax, 90	61.0	18.0
	borax, 120	65.0	19.0
Chehalis silt loam	untreated	48.0	15.0
Ferry-Morse	borax, 30	55.4	18.0
	borax, 60	47.0	17.0
	borax, 90	52.6	24.0
	borax, 120	63.0	22.0
Amity silty clay loam	untreated	54.0	19.4
Ferry-Morse	borax, 30	58.0	22.0
	borax, 60	59.0	23.0
	borax, 90	63.4	26.6
	borax, 120	66.0	25.0

One thing indicated is that the leaves offer a much better criterion of the boron content of the substrate than do the roots.

Table 4

The Willamette soil was definitely a better medium for beet growth than the Newberg and the increased rates of borax had a beneficial effect except in the case of the 20-pound application on the Willamette soil. There was no evidence of toxicity at 120 pounds, even though the plant growth in the experiment was rather slow. The increase is significant with regard to the untreated jars but does not follow the rate of application.

Field Experiments

The field experiments were conducted in cooperation with the soils department as a part of its soil fertility program and the data included in the tables are taken from trials in 1941. The beets were grown on Chehalis silty clay loam at the Horticulture Farm and on Lake Labish peat at the Hayes Farm. The soils were fertilized in the spring of 1941 and the crops were harvested in July. Canker counts were made by cutting twenty-five beets from each plot.

Table 4. Yield of Beets
Grown in Greenhouse Trial, 1942

Soil	Yield: Treatment in pounds per acre				
	Check	Borax 30	Borax 60	Borax 90	Borax 120
	grams	grams	grams	grams	grams
Willamette silt loam	13.6	12.1	16.8	16.1	18.3
Newberg sandy loam	4.3	6.3	6.2	7.3	7.25

Table 5

The per cent of cankered beets was found to be higher in the case of the 20-pound applications of borax on the Method of Application experiment, both broadcast and drilled, but otherwise increasing the boron applications decreased the per cent of canker progressively. On the Latin square experiment, the addition of boron caused a marked drop in the incidence of canker from 34 per cent on the untreated plots to 7 per cent on the boron plots. With the Lake Labish trial there is a great fluctuation in the per cent of canker and no agreement between rate of application and prevalence of canker.

The yield data from the Method of Application experiment show again that the results with the 20-pound applications of borax are at variance with the others and the yields on those plots are less than on the untreated plots. The yield from the other plots is consistently higher than the untreated one but does not follow the rate of application. The 40 pounds of borax applied in solution gave the highest yield, but the 80 pounds sprayed on did not do as well as the 80 pounds broadcast, which may indicate that there was slight toxicity at that concentration. The 160 pounds showed the lowest yield outside of the checks and the 20 pounds and may also indicate a definite toxicity.

Table 5. Per Cent of Canker and Yield of Table Beets with Different Fertilizer Treatments

Location	Treatment and Rate per acre lbs.	Canker per cent	Yield per acre tons
O.S.C. Horticulture Farm	untreated	12	1.37
	borax, 20 broadcast	16	1.35
	borax, 40 broadcast	8	1.72
	borax, 80 broadcast	7	1.83
	borax, 160 broadcast	0	1.62
	borax, 40 sprayed	8	1.95
	borax, 80 sprayed	4	1.76
	borax, 20 drilled	24	1.05
Hayes Farm, Lake Labish	untreated	37	19.63
	borax, 20 broadcast	36	20.27
	borax, 40 broadcast	16	24.43
	boric acid, 54 broadcast	12	25.23
	borax, 80 broadcast	28	25.23
	borax, 120 broadcast	24	22.72
	borax, 40 sprayed	16	23.52
	borax, 80 sprayed	44	23.68
	borax, 20 drilled	24	20.96
	borax, 40 drilled	24	19.20
O.S.C. Horticulture Farm	untreated	34	3.55
	NPK check	36	3.93
	boron	7	4.35

With the Latin square trial at the Horticulture Farm, boron significantly increased the yield over both the untreated check and the check with complete fertilizer.

The best agreement between yield and rate of application was found in the peat experiment on Lake Labish, where the only discordant results were with the 40 pounds of borax drilled in next to the seed and the 120 pounds broadcast. The 20 pounds broadcast gave a yield slightly less than the 20 pounds drilled; the 40 pounds broadcast was better than the 40 pounds sprayed or drilled; and the 80 pounds broadcast was better than the 80 pounds drilled but the same as the 54 pounds of boric acid, which would be equivalent to 80 pounds of borax. The 120-pound application proved to be too much and depressed the yield appreciably when compared to the 80-pound applications.

Table 6

There is good agreement between the rate of application and the boron content of the surface soil in all cases and the table shows that the boron has penetrated only a short distance beneath the plow layer. The peat soil had an average of 0.65 p.p.m. of available boron in the 20 - 40 inches, whereas the Chehalis soil had only 0.43 p.p.m. at the same depth. Little difference was

Table 6. Boron Content of Some Oregon Soils

Description of Sample	Treatment and Rate per acre	Boron Content of Soil — Depth in inches 0-7	7-20	20-40	40-50
	lbs.	p.p.m.	p.p.m.	p.p.m.	p.p.m.
Horticulture Farm, Chehalis silty clay loam	untreated	0.44	0.41	0.42	0.25
	borax, 20 broadcast	1.10	0.55	0.43	0.45
	borax, 40 broadcast	1.15	0.60	0.43	0.43
	borax, 80 broadcast	1.23	0.61	0.45	0.48
	borax, 160 broadcast	1.30	0.45	0.35	0.35
	borax, 40 sprayed	1.05	0.58	0.45	0.43
	borax, 80 sprayed	1.18	0.60	0.48	0.40
	borax, 20 drilled	0.95	0.55	0.43	0.43
Horticulture Farm, Chehalis silty clay loam	untreated	0.48	0.45	0.38	0.40
	0.90	0.90	0.55	0.45	0.35
Lake Labish Peat	untreated	0.53	0.55	0.55	
	borax, 20 broadcast	0.98	0.73	0.78	
	borax, 40 broadcast	1.15	0.82	0.60	
	borax, 80 broadcast	1.29	0.77	0.69	
	borax, 120 broadcast	1.28	0.90	0.75	
	borax, 40 sprayed	1.18	0.55	0.58	
	borax, 80 sprayed	1.20	0.82	0.63	
	borax, 20 drilled	0.88	0.50	0.58	
	borax, 40 drilled	1.09	0.73	0.72	

found between the same amounts of borax applied in various ways and the boron content of the soil.

Table 7

As was the case with the greenhouse experiments, there is little correlation between the boron content of the soil and that of the roots of the beets, but the leaves seem to be a fairly good indicator of the amount of available boron in the substrate. In only two instances did the leaf analyses show that an untreated plot had more boron than treated plots and that was with a 20-pound application. All other times the leaf content followed the soil content quite closely.

Table 7. Boron Analysis of Table Beets

Description of Sample	Treatment and Rate per acre	Boron content Leaves	Roots
	lbs.	p.p.m.	p.p.m.
Lake Labish Peat	untreated	54.5	15.5
	borax, 20 broadcast	58.4	18.3
	borax, 40 broadcast	57.6	18.7
	boric acid, 54 broadcast	60.0	16.0
	borax, 80 broadcast	64.0	22.0
	borax, 120 broadcast	68.0	21.5
	borax, 40 sprayed	62.0	19.0
	borax, 80 sprayed	67.0	21.5
	borax, 20 drilled	60.0	19.3
	borax, 40 drilled	58.0	18.5
Chehalis Loam, O.S.C. East Farm	untreated	53.8	21.0
	borax, 20	52.0	20.0
	borax, 40	57.8	22.0
	borax, 60	61.4	19.0
	borax, 80	64.0	30.0
Chehalis Silty Clay Loam O.S.C. Horticulture Farm	untreated	58.4	24.6
	borax, 20 broadcast	58.2	23.4
	borax, 40 broadcast	59.8	21.6
	borax, 80 broadcast	62.6	22.2
	borax, 160 broadcast	66.0	29.8
Method of Application Trial	borax, 40 sprayed	61.0	21.4
	borax, 80 sprayed	67.2	25.6
	borax, 20 drilled	59.0	22.8
Canned beets	untreated		15.6
	boron		18.4
Latin square	untreated	57.0	15.0
	NPK check	58.0	18.0
	boron	65.0	23.0

DISCUSSION

Determinations of the boron content of the roots and leaves of beets grown with different amounts of borax applied as fertilizer show that the parts per million of boron in the leaves follows fairly well the increased supply of boron in the soil, whereas there is little or no correlation between the field application and the boron content of the roots. These results are in conformity with other experiments which indicate that analysis of the leaves of plants presents a much better criterion of soil conditions of availability and absorption than does the analysis of the roots of the same plants. The leaves are the center of active metabolism of plants and any change that is made in the nutrient or physical substrate will be reflected first in that region, as is well-illustrated in the case of deficiency or toxicity symptoms, which are almost always most pronounced in the leaves.

The data show that soil applications of borax at 40 pounds per acre or less have little effect on the boron content of the leaves although even 20 pounds of borax may be quite sufficient in some years to give commercial control of beet canker. This would seem to indicate that the amount of boron which is required by the plant to maintain its normal healthy condition, free from canker, is not particularly large as compared to the supply found in a cankered beet and that an increase of only a few parts per million of boron may be sufficient to overcome a deficiency.

Water-culture experiments have demonstrated clearly that the range between deficiency, optimum, and toxicity is very small, a fact that would explain the inability to correlate closely canker with boron content. An application of 160 pounds per acre of borax gave a boron content in the leaves of 66 p.p.m. and entirely controlled canker, but a 20-pound rate showed less boron and more canker than in the untreated plots in 1941, whereas in other trials, 20 to 30 pounds is reported to have controlled the malnutrition troubles.

Analyses of the leaves of beets can be used as an estimate of the available boron content of the soil under the conditions which prevail at the time of sampling. From these figures, one can determine the boron requirement of the soil in relation to the growth of table beets and if the results show that the boron content of the plants is approaching a level which is close to the range of deficiency, a boron carrier should be applied.

While it is impossible to say that deficiency begins at a certain point, a range can be established which would provide an indication of the amount of boron that should be present in the plants in order to give a margin of safety. In the case of beets, this range would be in the order of 60 p.p.m. of boron in the leaves, and analyses which showed a concentration below that amount would indicate that it would be advisable to apply a boron fertilizer in order to safeguard against possible deficiency.

Soil Factors Affecting Boron Availability

Old soils, leached soils, and those derived from basaltic rocks were noticed by Powers (1939) to be especially acute in their deficiency in boron. This observation was confirmed by Cox (1940) insofar as the leached soils were concerned, when he removed added borax from soils by leaching with distilled water even a year after the borax was applied. Drying, followed by rewetting, substantially increased boron fixation.

Less boron deficiency was found by Schuster and Stephenson (1940) in the upper three feet of soil where the greatest portion of the humus was concentrated. Humus depletion seemed to aggravate the boron deficiency, which could be relieved by addition of sufficient compost to the soil.

The total boron content of the soil is not a reliable indication of the need for boron fertilization because, generally, less than five per cent of the total boron is in an available form, according to Berger and Truog (1939).

Anion exchange, molecular adsorption, and chemical precipitation may all take place in soils is the belief of Eaton and Wilcox (1939), but it has not been possible to designate which one, to the exclusion of the others, is operative in any given case.

Drought was found to increase boron deficiency, probably by decreasing its availability, according to Burrell (1938). Open, droughty soils, especially on southerly eroded areas, were reported by Baker (1941) to show greater boron deficiency than other soils. In the case of old cultivated soils, Brown and King (1939) found that alfalfa that had been fertilized with boron was not affected by drought, whereas check plots showed yellow top.

Soil reaction plays an important role in the availability of boron, as indicated by the statement of Midgley and Dunklee (1940) that the amount of fixation of boron depends on the degree of original acidity and the extent of subsequent liming. Liming acid soils fixed large amounts of borax, which would lead one to think that fixation in soils is chemical rather than biological. Powers (1939) found that in some cases where lime had been used in greenhouse experiments, boron was less effective, while sulphur lessened injury in field trials. Analysis of limed and unlimed soils for available boron in relation to boron deficiency symptoms by Ferguson and Wright (1940) showed a higher water-soluble boron content on the limed soils but also a greater evidence of boron deficiency symptoms. Raising the soil reaction by liming was supposed by Naftel (1938) to increase the population of microorganisms and to thus initiate boron deficiency by biological absorption. As a result, higher plants cannot compete successfully for sufficient boron for normal plant growth. The addition of sulphur to alkaline mucks overcame boron deficiency of celery in experiments conducted by Harmer (1940). The discovery that boron deficiency symptoms occurred at pH levels approaching 7.0 and became increasingly severe at higher values was made by Wolf (1939).

That the high boron requirement of beets, alkaline soil reaction, use of little or no manure, and deficiency of soil moisture are the factors that cause boron deficiency in beets was the conclusion of Raleigh, Lorenz, and Sayre (1941).

The opinion that the original boron content of the soil forming minerals and the boron losses due to crop removal and leaching are apparently among the controlling factors in determining the available boron content of soils was put forth by Purvis and Hanna (1940).

Data showing correlation between boron deficiency symptoms and active calcium content of the soil were presented by Cook and Miller (1939). They also believe that excessive leaching, as occurs on hill tops and in areas where there is a sandy subsoil horizon, is conducive to boron deficiency. Active calcium, organic matter, and clay content of soils were said by Muhr (1940) to play a part in determining boron availability.

In the present study, the relation of moisture to the incidence of boron deficiency symptoms has been amply borne out by observations made in wet and dry years. When there was a good supply of water available to the growing plants the amount of canker was much less than when the moisture supply was limited. The mechanism of this decrease in deficiency is quite likely dependent upon the increased amount of available boron brought into solution by the water since the total boron content remains essentially the same. The application of relatively large amounts of boron may be necessary during dry periods if canker is to be controlled, whereas a relatively small application may be entirely adequate under moist conditions. The danger of using too much boron is minimized in the case of beets because they have been shown to be quite tolerant to heavy applications.

Leached soils, such as Newberg, Chehalis, and peats, respond better to boron additions than do the heavier valley soils, such as Willamette and Amity, although in dry years the latter will also need fairly large applications in order to correct a deficiency. The very fact that the beets produced in the Willamette Valley are usually grown on one of the first-mentioned soils indicates the necessity for a canker-control program.

The boron analyses bear out the contention that more of the available boron is found in the upper layers than in the lower. In the case of the peat soil, the boron content was the same at all depths, which would be expected if the available boron were related to humus, as is believed by a number of investigators.

A mineral soil having as much available boron as the subsoil of the Lake Labish peat contains would be well off as regards boron, since the figure nearly equals that found with the 20-pound application of borax on the Chehalis silty clay loam. The Newberg and Chehalis soils have only slightly less available boron than the Amity, but deficiency symptoms appear sooner and are more severe on the first two soils than on the last, partly due to the higher soil reaction on the Newberg and Chehalis, perhaps.

Perhaps the most important of the previously-named factors from the standpoint of the interest it has aroused is that concerning the influence of liming upon boron availability. Although it is generally agreed that liming often produces a boron deficiency in soils, there is a difference of opinion as to the mechanism by which the deficiency is produced. Midgley and Dunklee have presented strong evidence in support of the theory that liming causes borate fixation and have introduced a new idea in attributing to the organic lignin fraction of the soil an important role in this fixation. Others attribute the loss of available boron in limed soils to the increased activity of the soil microbes, believing that the organisms themselves are capable of utilizing the pound or two of boron available in most soils. Possibly both are right, the borate being absorbed by the organic fraction, released as this fraction is decomposed, and then utilized by the microbes.

There is still another explanation of the influence of lime in producing boron deficiency. An environmental change which causes an increased rate of plant growth may deplete the soil of any available nutrient to such an extent that a deficiency of this nutrient is produced. This would be especially true of boron since the range between the optimum and the toxic concentrations of this element in the soil solution is so narrow. Those who support this hypothesis point to the fact that a majority of the known boron-deficient areas in this country occur in regions of acid soils. Since these soils are believed to have been originally low in boron content and are known to respond to lime, this explanation seems at least logical.

The conditions under which soils are formed are also believed to influence the content and availability of boron. Although comparatively little data are available at present on this subject, that which we do have is of considerable interest. Results of chemical analyses show that chernozem, desert, and prairie plains and the podzol soils are low.

The variation in total boron content of soils, mentioned by Dr. Powers, must of necessity have some influence upon the available boron content although it has been found to be undependable by several workers. Berger and Truog found that less than five per cent of the total boron in soils is usually available to plants, and since this percentage varies with different soils, they consider extraction with boiling water a better method for arriving at the available boron content.

The tolerance of soils to applications of borax had been found to correlate fairly well with organic matter content and exchange capacity. Working with soils from several states, Purvis has found that ten pounds of borax was sufficient to produce injury to snap beans on a sandy loam having an organic carbon content of 0.61 per cent and an exchange capacity of 4.1 m.e. per 100 grams of soil, while 100 pounds of borax per acre produced only slight injury on a fine sandy loam having an organic carbon content of 4.38 per cent and exchange capacity of 15.2 m.e. per 100 grams of soil. This difference may have been due to organic fixation or to high acidity.

The frequent occurrence of boron deficiency in the light sandy soils of the Atlantic Coastal Plain is no doubt accounted for by the low original boron content of these soils and by the intensive cropping systems to which many of them have been subjected. The use of synthetic fertilizers may also have played a part, but hardly an important one. Although the various fertilizer salts may contain some boron as shown by analyses, with the exception of the unrefined American potash salts used in this country during the World War, it is doubtful if any natural fertilizer material in the quantities ordinarily used supplies as much boron to the soil as is removed by crops. One experimenter mentioned that manure even in excess of ten tons per acre did not prevent the appearance of boron deficiency with alfalfa in Connecticut.

There is another factor which may be of very great importance, both from the standpoint of its influence upon the development of boron deficiency and upon the results of certain fertilizer experiments of the past. As mentioned in the discussion of liming, any environmental change which brings about an increased rate of growth is conducive to the development of boron deficiency. In other words, the available boron content of a soil must be kept in the proper ratio with the available supply of other nutrients for optimum plant growth. Forced boron deficiencies caused by the application of quick-acting fertilizers, or by rains after periods of drought, have been noted in the field by a number of workers.

Functions of Boron in the Plant

Boron deficiency causes a progressive increase in acidity and ammonium nitrogen in scattered parenchyma cells of the stem tips of cotton, according to Wadleigh and Shive (1939). A corresponding degneration of the protoplasm may be due to the altering of the normal course of protein synthesis.

Boron accelerates the absorption of cations and inhibits the take-up of anions, according to Rehm (1937). This may be brought about by a displacement of the isoelectric point of certain plasma colloids toward the acid side through the formation of complex boric acid compounds.

A higher rate of carbon dioxide output is associated with either high or low concentrations of boron in the nutrient media than plants treated with the optimum boron content in experiments conducted by Phillips (1938).

The importance of a proper calcium-boron ratio in plants was emphasized by Drake, et al. (1941) when they found that a ratio of 1,340:1 in tobacco plants gave normal growth, whereas a 1,500:1 ratio was correlated with severe boron starvation symptoms. Following this same line of investigation, Shive (1941) found that there was almost perfect correlation between the boron of the tissues of corn and the soluble calcium content of the tissues.

The fact that boron also affected the pectin and fat content of the cells was noted by Shive. Low boron meant much pectin and no fat, high boron meant much fat and no pectin, and optimum boron meant both pectin and fat could be found in the plant.

Boron appears to give elasticity to cell membranes and to aid cell division (Johnston and Dore, 1929), prevents swelling and blocking of roots (Sommer and Sorokin, 1928), is important in nitrogen metabolism and aids development of nodules and nodule bacteria (Brenchley and Thornton, 1925), lessens the effect of drought and improves the keeping quality of fruit (McWhorter, 1938). Warrington

(1926) found that boron prevents the breakdown of conducting tissues, and Johnston and Dore (1929) learned that it affects carbohydrate translocation and pectin formation and the amount of calcium in tissues. Observation by Powers (1936) showed that boron promotes branching and blooming and aids longevity of alfalfa, while Eaton (1940) reported that boron is essential for auxin formation in plants. Pollenization (Vasil'ev, 1937) and seed production (Piland and Ireland, 1941) may be helped by boron. McLean and Hughes (1936) considered that the role of boron in the plant was that of a regulator or activator of metabolic processes. Carotene in alfalfa was increased 30 per cent and chlorophyll 50 per cent in Oregon studies (Powers, 1939). With beets, a deficiency has been seen to cause an influx of red coloring pigments (the anthocyanins) into the leaves.

Boron and Canker

The means by which boron serves to prevent root canker of beets is not thoroughly understood but it is probably related to the ability of boron to give elasticity to cell membranes which, in turn, prevents the characteristic disintegration and ultimate breakdown of the tissues. While the beet is growing rather slowly, a fairly small amount of boron is sufficient for its needs, but when the growth is rapid on soils low in boron, the plant cannot absorb quantities large enough to fulfill all its requirements and breakdown soon follows. This is brought out in the observation that boron deficiency symptoms are more pronounced when a wet period with rapid growth follows a droughty period. It is further substantiated by experiments showing that the addition of boron to a nutrient solution that has not previously contained boron and in which the plants have shown cell disintegration will cause an almost complete recovery of the plant, with the exception of the cankered area.

Studies of the anatomical structure have shown that plants grown in nutrient solutions entirely devoid of boron exhibit frequent disintegration of phloem and ground parenchyma, poor development of the xylem, hypertrophy, discoloration, and disintegration of cambial cells, and, occasionally, complete breakdown of conducting tissue. Boron deficiency symptoms are usually seen in the meristematic region of the plant where a fresh supply of the element is constantly being required.

Boron and Yield

Experiments conducted by the soils department have given yield increases of beets with boron fertilizers up to 80 pounds of borax per acre, while with greater applications there is a slight drop. This greater tonnage would indicate that additions of boron above that necessary for control of canker are economically justified, up to a certain point, although the data at hand is not inclusive enough to allow any definite statement one way or another. One thing is certain, that the adage "if a little is good, a lot is better" does not apply to boron, as has been brought out in numerous instances where toxicity has resulted from over-zealous applications.

Beet growers have recognized the quality of beets in Oregon is dependent upon the fertilization of fields with borax or boric acid and that an epidemic of canker can ruin a season's crop.

<u>Use of Boron in the Control of Beet Canker</u>

The chief boron carriers are borax and boric acid. The former contains approximately two-thirds as much boron as the latter but is usually cheaper and more readily applied because of its granular physical condition. The recommended rate of borax application is 50 pounds per acre broadcast and somewhat less when drilled.

Borax may be applied alone by means of a cyclone-type grass seeder, it may be evenly mixed with another fertilizer and broadcast before seeding, or it may be included in a fertilizer applied as a side dressing after the plants are seen in the row.

The duration of the treatment will vary with the climate, soil, crop yield, rate, and method of application, and other factors. The applied boron may be: (1) removed by the plant; (2) fixed by the soil in unavailable form; (3) taken up by the plant; or, (4) leached away. A 50-pound application when broadcast will last about two years.

SUMMARY

Greenhouse and field experiments were conducted to determine the effect of boron on the incidence of canker and yield of table beets. Various strains of table beets were grown to detect differences in susceptibility to canker and effect of boron. Plants and soils were analyzed to see if there were any correlation between boron content and the prevalence of canker, as well as the growth of beets.

Boron applications proved effective in controlling beet canker although the extent of the control was not proportional to the rate of application of the boron fertilizer. Yields were increased with increasing rates of application up to 80 pounds of borax per acre, after which there was a drop in yield.

Plant analyses, when compared to per cent canker and yield, indicate that 60 p.p.m. of boron in leaves is the dividing point between deficiency and optimum boron content. The leaves seem to offer a much better criterion of available boron in the soil than the roots. The various ways by which boron influences the anatomy and metabolism of the plant are reviewed and elaborated upon with reference to the causes of beet canker.

Soil analyses show that there is a good agreement between rate of boron application and the available boron in the soil. Lake Labish peat and Amity silty clay loam contain more available boron than the Chehalis and Newberg soils used. The factors thought to determine the availability of boron in the soil are considered in the light of conditions in Oregon.

Time, rate, form, method, and duration of application are mentioned.

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