Boron Nutrition in the Growth and Sugar Content of Sugarbeets

JAMES VLAMIS AND ALBERT ULRICH[1]

Received for publication July 6, 1970

The system of analyzing plant tissues chemically has proven very useful in establishing the nutrient status of plants for such elements as nitrogen, phosphorus, potassium and other macronutrients in sugarbeet plants. There is reason to believe that it may be even more useful for some of the micronutrients.

Recent work has shown that a content of 10 ppm in mature blades characterizes a critical value of manganese in sugarbeets (14)[2]. Further research with zinc has given a range of 8-10 ppm, also in mature blades (11). With iron it has been shown that 55 ppm in young and mature blades represents a deficiency level (9).

This study was made to determine the growth, boron content of the tissues and sugar production of sugarbeet plants grown in nutrient solutions covering a wide range of boron supply.

Materials and Methods

Plant culture

Hybrid sugarbeet seeds (F58-554H1-MS of NB1 X NB4) were treated with a fungicide, Phygon XL, at a rate of 1 gram per 100 grams of seed. They were planted in vermiculite in the greenhouse and irrigated with nutrient solution without boron (Table 1). The salts used were chemically pure and prepared in distilled water. No further purification of salts or water was necessary to achieve boron deficiency of a very acute form.

Table 1.—Chemical composition of nutrient solution added initially and at two intervals in the experiment.

Salts added in meq./l.		Microelements in mg/l.	
$Ca(NO_3)_2$	5.00	Mn, as $MnSO_4 \cdot 4H_2O$	0.25
KNO_3	2.50	Zn, as $ZnSO_4 \cdot 7H_2O$	0.025
$MgSO_4$	2.00	Cu, as $CuSO_4 \cdot 5H_2O$	0.010
KH_2PO_4	1.00	Mo, as MoO_3	0.005
K_2SO_4	0.50	Fe, as EDTA	2.5
NaCl	0.50	Boron (see Table 2)	

Two weeks after planting, the seedlings were transferred to cork rings and supported by dacron fiber at the rate of one seedling per cork. Three seedlings were placed in three-hole

---

[1] Plant Physiologists, University of California, Berkeley.

[2] Numbers in parentheses refer to literature cited.

masonite covers mounted on 20-liter containers previously painted with aluminum paint on the outside and Amercoat No. 33 on the inside. The masonite lids were painted with aluminum on the upper surface and valspar on the lower surface. The containers were filled with half-strength Hoagland's solution, slightly modified, as shown in Table 1.

The established Hoagland (H) rate of boron is 0.5 ppm and this was used as the base solution. Boron rates were reduced by multiples of one half for seven treatments until 1/128 H boron was reached. An additional treatment in which no boron was added constituted the lowest boron level of the experiment. Five replicates of each treatment were set up making a total of 45 pots. Three weeks later another quantity of half-strength Hoagland salts (minus B) was added and this was repeated in two weeks.

The experiment was conducted in a smog-free greenhouse with clear glass from late March until the middle of May. Observations were made during this period for the sequence of appearance of deficiency symptoms. The nutrient solutions were maintained at a pH of 5.3 to 6.5 and distilled water was added at intervals as required.

Harvesting

The plants were harvested 7 weeks after transplanting to the 20-liter containers. The tops were cut off at the first leaf scar, fresh weights obtained and the leaves separated into three age groups—young, mature and old. Young leaves were those which had not reached full size while old leaves showed one or more signs of senescence. The leaves between the young and old were classified mature. The leaves were further divided into blades and petioles. A miscellaneous category covered dead or drying leaves. The roots were separated into fibrous and storage roots.

Preparation of samples

The storage roots were quick-frozen in dry ice and stored at -15°C for future sugar analysis. The other plant parts were placed in paper bags and dried at 70°C in a forced-draft oven for 48 hours. The dried material was weighed, ground in a Wiley mill with a 40-mesh screen and stored in plastic vials for analysis.

Chemical analysis of plant material

The samples were analyzed for boron by the curcumin method. Some material was also analyzed by the carmine method for verification. All other analyses were made by established colorimetric methods or flame emission spectroscopy (6).

Results

Visual symptoms of boron deficiency

The first signs of deficiency appeared within a week in the treatments where no boron was added. The growing point of the shoot and root failed to grow and the plant remained stunted. New buds appeared in the growing point of the shoot and as each failed, subsequent ones suffered the same fate until the growing point consisted of a cluster of dead or dying black buds. The roots failed to elongate beyond their initial size at transplanting.

As the plants developed, those growing in the low boron rates became retarded in growth and showed deficiency symptoms in sequence as the solutions ran out of boron. The young leaves curled and turned black. The old leaves showed surface cracking along with cupping and curling. Black juice oozed from the midribs of the leaves. When the growing point failed completely, it formed a heart rot. Some or all of these symptoms appeared from the 1/8 Hoagland rate of boron down to zero boron.

The fibrous roots were darker in the deficient plants and when the tap roots were cut in cross and longitudinal section, black streaks appeared, many of them in the conducting tissues. Detailed photos of B deficient sugarbeet plants are available elsewhere (1,13,15).

Effects of boron

The symptoms, fresh and dry weights, and sucrose content of the storage roots are given in Table 2 and Figure 1. Moderate symptoms appeared at the one-eighth Hoagland level of boron with only a slight decrease in growth. All higher levels of boron were free of symptoms. Below the one-eighth level, symptoms became severe or acute and the yields were lower.

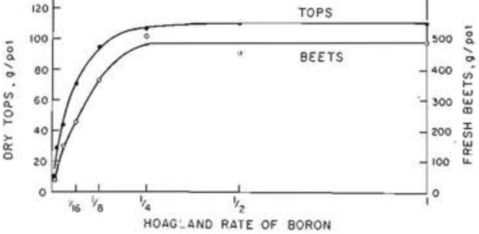

Figure 1—Dry weights of tops of sugarbeets as a function of initial Hoagland boron rate. Unit strength of Hoagland's solution contains 0.5 ppm boron.

Table 2. – Effect of boron on growth of tops and roots of sugarbeet plants and sugar content of storage roots. *

Boron Supply			Tops		Storage roots		Fibrous roots	
Hoagland rate	Boron mg. per 20 liters	Symptoms	Fresh wt.	Dry wt.	Fresh wt.	Sucrose content	Fresh wt.	Dry wt.
			gm	gm	gm	%	gm	gm
–	0	acute	- -	<1	–	–	–	0.1
1/128	.078	acute	46	10	26	4.2a**	14	1.1
1/64	.156	acute	166	29	87	4.9a	35	2.8
1/32	.312	acute	292	43	149	4.8a	60	5.0
1/16	.625	severe	553	71	229	5.8	73	7.0
1/8	1.250	moderate	732	95	366	7.6b	91	9.4
1/4	2.500	none	943a	107a	512a	8.1bc	103a	10.9a
1/2	5.000	none	1009ab	109a	457a	9.1d	102a	11.1a
1	10.000	none	1098b	111a	496a	8.5cd	115a	11.8a

* Data are means of 5 replications.

** Duncan's multiple-range test. Means within a column followed by the same letter do not differ significantly at the 5% level.

The weights of fibrous and storage roots, and the sugar content of the beets reached a plateau above the one-eighth Hoagland boron level and decreased rapidly below this point.

Calibration of tissue boron versus yield

The results of the boron analyses of the various plant parts are presented in Table 3. When the data were plotted against yield, curves were obtained which delineated the zones of deficiency and adequacy, with a transition zone in between (Figures 2-4). For the purpose of choosing the most suitable plant part

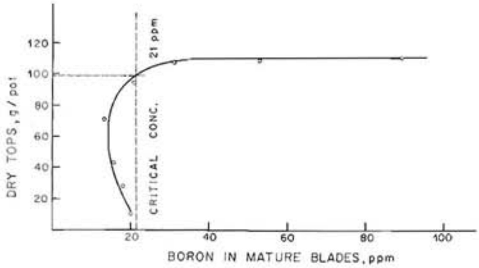

Figure 2—Relation of dry weights of tops to boron content of mature blades. The critical concentration line crosses the curve at ninety percent of maximum yield.

Table 3. - - Boron content in PPM of petioles, blades, fibrous roots and storage roots of sugarbeet plants grown in nutrient solutions. *

Hoagland	Tops dry	Blades			Petioles			Roots	
Boron rate	wt. gms.	Young	Mature	Old	Young	Mature	Old	Fibrous	Storage
0	<1	— **	—	—	—	—	—	—	—
1/128	10	49.6a***	20.6ab	43.6c	—	—	22.4c	—	—
1/64	29	37.5a	18.4ab	26.4a	—	24.3b	21.1c	—	—
1/32	43	39.5a	16.0ab	26.0a	15.8ab	17.0a	14.6ab	—	—
1/16	71	37.5a	13.9a	23.8a	13.4a	15.9a	18.2bc	34.6a	35.0a
1/8	95	26.6a	21.1b	30.1ab	18.8b	14.8a	12.1a	34.6a	33.3a
1/4	107a	30.6a	30.9	41.3bc	19.1b	19.6abc	20.7c	38.5ab	34.8a
1/2	109a	48.3a	53.4	71.7	24.8c	27.3c	31.9d	41.4ab	40.1a
1	111a	77.5	89.6	114.2	31.6	34.1	34.0d	44.1b	46.1a

* Data are means of 5 replications.

** Insufficient material for analysis.

*** Duncan's multiple-range test. Means within a column followed by the same letter do not differ significantly at the 5% level.

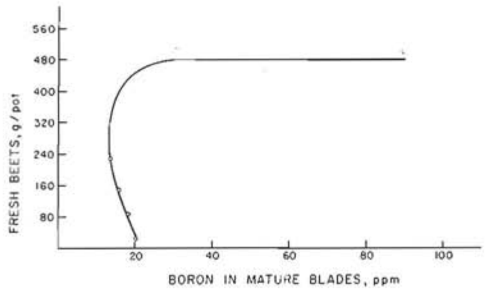

Figure 3—Beet root weights in relation to boron content of mature blades.

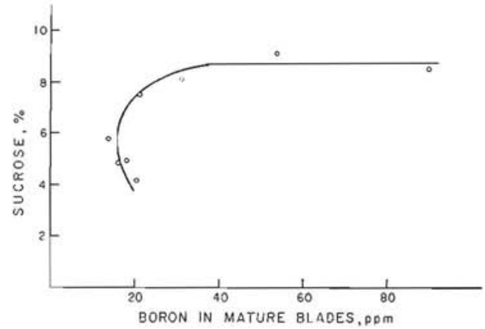

Figure 4—Percent beet sucrose plotted against boron content of mature blades.

to be used in determining the boron status of the sugarbeet plants, the preferred curve is one which has smooth contours, a minimum of point scatter, and a sharp break in the zone of transition.

By inspection it was found that the mature and old blades produced the best curves of yield versus boron content. The critical boron concentration was taken to be the concentration in the mature blades when the yield was 90% of the maximum. Referring to the curve of yield versus boron content of the mature blades, a critical concentration of 21 ppm boron was obtained. It is not likely that this figure is a rigid value separating a deficient plant from one with an adequate boron supply. It would be more realistic to choose this as a mid-point in a critical zone of deficiency whose magnitude lies within the range of 15 to 30 ppm boron.

The boron content of the mature blades plotted against beet yield and percent sucrose likewise produced curves which are suitable for diagnostic purposes. In other words the boron status of mature blades is a very good indicator of sugarbeet plants supplied adequately or insufficiently with boron with respect to both yield and sucrose production.

At the higher boron rates, the boron content of the mature petioles is much less than in the mature blades, being less than half in many cases. As deficiency values are approached this difference diminishes or even reverses, i.e., at deficiency levels the petioles are higher than the blades. This relationship may provide an even better measure of boron status than simply considering the boron content of these tissues. A ratio of boron in mature blades: petioles above one would indicate an adequate supply while a ratio less than one would fall in the deficient zone.

As first shown by Brandenburg (1) the boron content in general increases with physiological age of tissues, the older the tissue the higher the boron. This does not apply as well at the very deficient levels but the results here are a little more erratic so no firm conclusions can be made in this region. It is interesting to note that in the fibrous roots and the beet pulp, the boron content is of the same order of magnitude and parallels that found in the petioles.

Discussion

The Piper-Steenbjerg effect

In all cases where curves were obtained from plots of yield versus boron content, a Piper-steenbjerg effect (10,12) was noted. This refers to the reversal in the direction of the curve in the deficient areas. Normally it would be expected that as nutrient supply is decreased to the point where plant growth is retarded, the tissue content of boron would decline to reflect this. This holds true except in some cases, at extreme deficiencies, the content of the deficient nutrient increases even though the yield continues to decrease. This is what we find with boron; and the same phenomenon has been found previously by Piper and Steenbjerg with copper (10,12) and by Rosell and Ulrich with zinc (11).

The explanation for this effect given by Steenbjerg (12), is that under conditions of acute deficiency the proportion of conducting and supporting tissues decreases and since these do not contain as much of a nutrient as the more active, living cells then the nutrient content appears higher. This is a plausible explanation but it could be that this effect is simply an artifact. The effect may be an apparent one, that, due to the breakdown of cells and tissues in acute deficiencies there is an actual loss in dry weight and since the mineral content does not change, the net effect is to give an increase in mineral content as parts per million. However, it will take a specially designed experiment to show what is actually taking place.

A very strong Steenbjerg effect could nullify the value of tissue analysis. A given analysis for a nutrient could be read off two parts of the curve leaving uncertainty as to whether it represents the upper part of adequate supply or the lower, backlash curve representing acute deficiency. In the latter case the presence of symptoms provides a protection against confusion of the nutrient status of the plant. An additional reason why mature blades were chosen as the most suitable tissue for diagnostic purposes was the presence of a minimal Steenbjerg effect compared to the other tissues.

Nutrient interactions

In an experiment where one nutrient is varied and all others are supplied at an adequate rate, it is inevitable that the content of some nutrients in plants grown at low levels of the variable nutrient will increase sharply. This is shown clearly in Figure 5 where the K content of mature blades is plotted against boron in the same tissues.

The K curve has the shape which may be anticipated. In the deficiency zones of boron, as the growth was restricted the content of K rose sharply. Where boron was adequate the curve is horizontal at a lower level. The explanation for this is that the increase in plant growth, accompanied by a lowering of nutrients in solution, exerts what is called a dilution effect. This may be mistaken for a genuine nutrient interaction whereas, in fact, it may only be a reflection of growth intensity and nutrient supply. A good example of a bonafide interaction where a deficiency of one nutrient produces a sharp increase in another is that of high nitrate in tissues produced by molybdenum de-

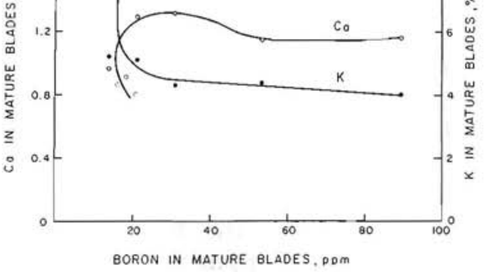

Figure 5—Calcium and potassium content versus boron content of mature blades.

ficiency (8). It is extremely doubtful if such a development is present here with K in relation to boron deficiency.

The Ca curve in Figure 5 shows just the opposite of the previous situation and we find Ca increasing in the tissues under conditions of improved growth and boron supply. Clearly this cannot be ascribed to a dilution effect since growth and Ca content both increased. The disorder created by an inadequate boron supply has adversely affected the accumulation of Ca in the tissues.

This effect is of more than passing notice because Ca and B give remarkably similar symptoms and strong interaction (7). It suggests the possibility that Ca and B are acting in closely related functions in the cell walls or the cell membrances, in as much as they do not occur in significant amounts in the cell sap.

The results of nitrate, sulfate and phosphate analysis (Table 4) show that these nutrients tend to follow the pattern of Mg and K, that is, to increase as the amount of growth decreases from boron deficiency.

Previous work has demonstrated a wide range of boron content in deficient sugarbeet plants. Eaton obtained a range of 19 to 35 ppm boron in the blades of deficient plants grown in sand cultures (4). Similar experiments by Hughes produced a range of 15 to 18 ppm in deficient leaves and intermediate values of 27 to 83 ppm boron (5). Using soils in pot cultures, Yang obtained 20 ppm in deficient leaves and 40 to 65 in healthy tissues (17). Leaves taken from plants grown in the field have a boron content varying from 4 to 30 ppm boron in deficient tissues (1). Several workers have reported decreases in beet yield and sugar content in sugarbeets deficient in boron (2,3,16).

The work presented here attempts to narrow the range of deficiency for diagnostic purposes and to decrease the overlap in boron content that is encountered in deficient and sufficient plants. This is done by separation of tissues into physiological age classes and the leaves into blades and petioles. When the results are plotted on a graph of yield versus boron content, a curve is obtained which readily separates the region of deficiency from sufficiency, with a narrow transition zone separating the two regions.

Of the tissues sampled, the mature blades appear to be the most suitable for determining the boron status of the plants. The data reveal that 15 to 30 ppm represents the critical range for boron. Beet root yields and sucrose concentration are likewise related to the boron analyses of the mature blades.

Table 4. — Macronutrient content in percent of mature blades of sugarbeet, plants grown in nutrient solutions. *

Hoagland	Cations			Anions		
Boron rate	Ca	Mg	K	NO_3-N	PO_4-P	SO_4-S
1/128	.80a**	1.16a	8.4	.50a	.79ab	.21a
1/64	.91ab	1.18a	7.5a	.47a	.85a	.19ab
1/32	.86a	1.11ab	7.1a	.63	.82a	.19ab
1/16	.96ab	1.00ab	5.2bc	.50a	.59c	.16bc
1/8	1.29c	.87bc	5.1bc	.27b	.44	.16bc
1/4	1.31c	.82bc	4.3d	.18b	.68bc	.11cd
1/2	1.15bc	.65c	4.4cd	.18b	.66c	.09d
1	1.16bc	.66c	4.0d	.18b	.67bc	.07d

* Data are means of 5 replications.

** Duncan's multiple-range test. Means within a column followed by the same letter do not differ significantly at the 5% level.

Summary

Sugarbeet seedlings were transplanted from boron-free vermiculite to a series of eight nutrient solutions ranging from 0.5 ppm boron to lesser amounts in multiples of one half. An additional series received zero boron. All treatments were replicated five times. Distilled water and C.P. grade of salts were used. The plants were grown in painted, 5-gallon containers, each containing three seedlings supported on masonite lids. Aeration was provided by means of soft glass tubing.

The plants were harvested 7 weeks after transplanting and symptoms had appeared in six of the treatments. The shoots were divided according to physiological age-young, mature and old leaves, and further separated into blades and petioles. The tissues were analyzed for B, Ca, Mg, K, nitrate-N, phosphate-P and sulfate-S. The storage roots were separated from the fibrous roots and analyzed for sucrose.

The mature blades were found to be the most suitable tissues for assessing the B status of sugarbeet plants by virtue of a sharp separation of deficient from sufficient status, minimum variability and least interference from the Piper-Steenbjerg effect. The critical concentration of B in oven-dried mature blades was found to be in the range of 15 to 30 ppm.

The blades had a higher B content than the petioles where the B supply was adequate but this relation was reversed in the deficient plants. The highest values of B occurred in the older leaves. The lowest B content was in the fibrous and storage roots.

The amount of Mg and K was highest in the most deficient plants and leveled off when B reached an adequate level. This was interpreted as a dilution effect. A reversal of this situation was shown by Ca which reached the lowest levels in the deficient plants.

Storage and fibrous root growth parallel the development of the shoot. The sucrose content of the storage roots started to decrease at about the same point where limiting B resulted in a drop in yield.

Literature Cited

(1) BRANDENBURG, E. 1940. Ueber die Grundlagen der Boranwendung in der Landwirtschaft. Phytopath. Zeitschr. 12: 1-112.

(2) CAMPBELL, LEO. 1940. Boron deficiency of sugar beets in the Puget Sound District of Washington. Am. Soc. Sugar Beet Technol. Proc. 2: 213-216.

(3) COOK, R. L. 1940. Borax as a control for heart rot of sugar beets. Am. Soc. Sugar Beet Technol. Proc. 2: 229-240.

(4) EATON, F. M. 1944. Deficiency, toxicity, and accumulation of boron in plants. J. Agr. Res. 69: 237-277.

(5) HUGHES, J. D. 1959. A note on foliar diagnosis of boron deficiency in beetroot. Queensland J. Agr. Sci. 16: 85-86.

(6) JOHNSON, C. M. and A. ULRICH. 1959. Analytical methods for use in plant analysis. Calif. Agric. Expt. Sta. Bull. 766.

(7) MINARIK, C. E. and J. W. SHIVE. 1939. The effect of boron in the substrate on calcium accumulation by soybean plants. Am. J. Bot. 26: 827-831.

(8) MULDER, E. C. 1948. Importance of molybdenum in the nitrogen metabolism of microorganisms and higher plants. Plant and Soil 1: 94-119.

(9) NAGARAJAH, SELLAPPAH and ALBERT ULRICH. 1966. Iron nutrition of the sugar beet plant in relation to growth, mineral balance, and riboflavin formation. Soil Sci. 102: 399-407.

(10) PIPER, C. S. 1942. Investigations on copper deficiency in plants. J. Agri. Sci. 32: 143-178.

(11) ROSELL, RAMON A. and ALBERT ULRICH. 1964. Critical zinc concentrations and leaf minerals of sugar beet plants. Soil Sci. 97: 152-167.

(12) STEENBJERG, F. 1951. Yield curves and chemical plant analyses. Plant and Soil 3: 97-109.

(13) ULRICH, ALBERT and F. JACKSON HILLS. 1969. Sugarbeet nutrient deficiency symptoms. Univ. Calif. Div. Agric. Sciences. Berkeley, California.

(14) VOMEL, A. and A. ULRICH. 1963. Die Blattanalyse zur Ermittlung von Mangan - Mangel bei Rüben. Z. Pflanzenernähr. Düng Bodenk. 102: 28-45.

(15) WALLACE, T. 1961. The diagnosis of mineral deficiencies in plants. (2nd ed.) H. M. Stationery Office, London.

(16) YAKOVLEVA, V. V. 1947. The influence of boron on the biochemical changes in the roots and leaves of the sugar beet. Doklady Akad. Nauk. SSSR. 58: 625-627. (Chem. Abstr. 45: 8091, 1951).

(17) YANG, T. 1960. A study on the boron requirement of the sugar beet. Taiwan Sugar Exp. Sta. Rept. 21: 17-25. (Biol. Abstr. 36: 21920, 1961).