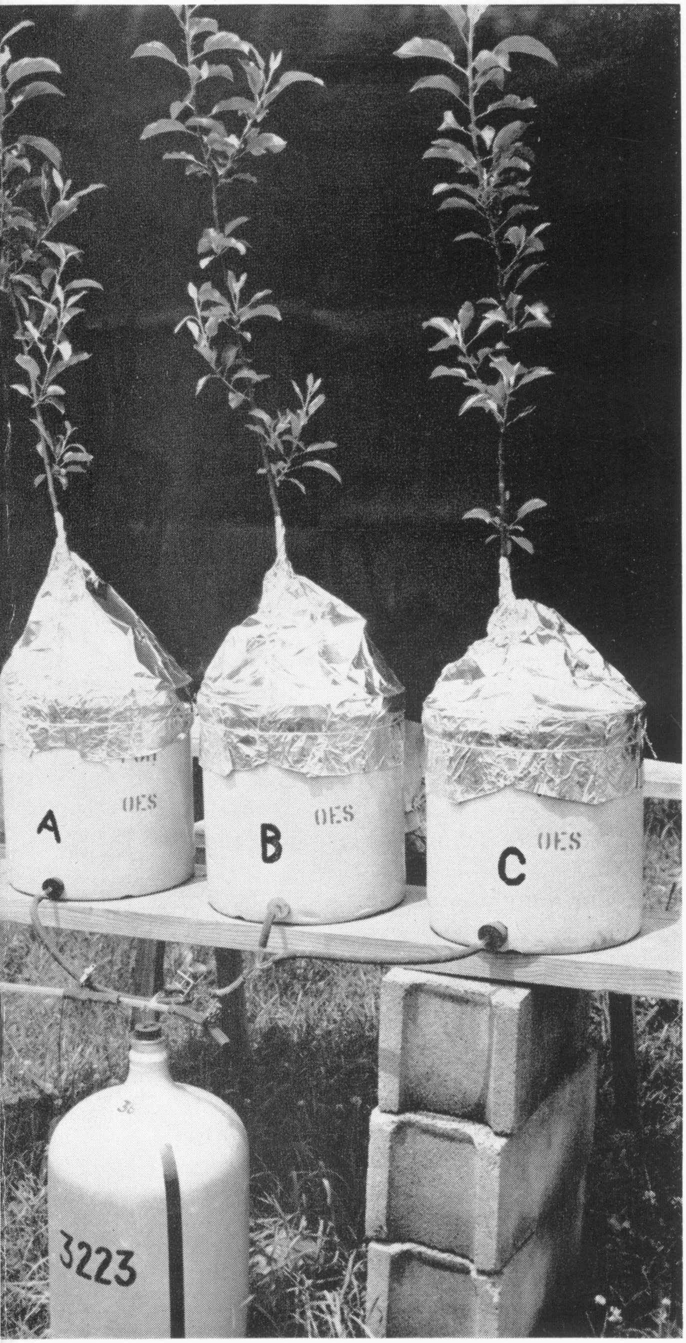
RESEARCH BULLETIN 754 JANUARY 1955



Studies on the BORON Requirements of YOUNG APPLE TREES Grown in SAND CULTURE

JAMES M. BEATTIE

OHIO AGRICULTURAL EXPERIMENT STATION
Wooster, Ohio

CONTENTS

* * * *

STUDIES ON THE BORON REQUIREMENT OF YOUNG APPLE TREES GROWN IN SAND CULTURE

JAMES M. BEATTIE

INTRODUCTION

In 1948 a survey was made of the nutrient status of commercial apple orchards in Ohio. In this survey a number of orchards were found with foliage containing less than 20 ppm of boron on a dry weight basis (5). Other investigations have cited this as a critical concentration for boron in apple foliage below which response may be obtained from the application of boron (1, 2, 24). None of the orchards in the Ohio survey, however, exhibited the specific visual symptoms characteristic of boron deficiency. Hence it was believed that the boron requirement of apple trees should be further investigated. The present work is a study of the influence of other ions upon boron accumulation. Specifically, it deals with the influence of differential levels of calcium, magnesium, potassium, and boron supply upon the accumulation of boron and upon the growth of young Rome Beauty apple trees grown in sand culture.

REVIEW OF LITERATURE

It has been observed that boron deficiency often occurs on alkaline or over-lime soils (16, 17, 23). This observation suggests the possibility of a physiological relationship between boron and calcium nutrition. The existence of such a relationship was suggested by Brenchley and Warington in 1927 (8). Their findings showed that although an ample supply of calcium was present at the root surfaces it could not be utilized by plants in the absence of boron. The relationship between calcium and boron has since been investigated by a number of workers (9, 12, 14, 15, 18) and their data support the earlier conclusions of Brenchley and Warington.

The work of Reeve and Shive (18) showed that potassium in the substrate also had an influence on the accumulation of boron in plant tissues. They found boron accumulation increased as the potassium supply was increased. Thus at high levels of boron supply high potassium increased the severity of boron toxicity symptoms. On the other hand, Chapman and Brown (11) working with citrus observed boron toxicity in the minus potassium cultures. Jones and Scarseth (14) have suggested that the influence of potassium on boron accumulation is indirect working through the effect of potassium on the absorption and accumulation of calcium.

The work of Shear, Crane, and Meyer (20) with tung trees grown in sand culture indicated that high concentrations of calcium, magnesium, and potassium relative to boron in tung foliage was conducive to the occurrence of boron deficiency whereas low concentrations of these elements relative to boron resulted in boron toxicity. Furthermore, high $\frac{Ca\ K}{Mg}$ and $\frac{Ca\ Mg}{K}$ ratios of foliage contents of these elements resulted in boron toxicity. These data appear to be in good agreement with mathematical ratios calculated from the data of Chapman and Brown (11).

The results of these investigations leave little doubt as to the existence of physiological relationships between boron and the cations calcium, magnesium, and potassium. Because the majority of these studies dealt with boron vs. a single other element it is believed that a full and adequate interpretation of the data is not possible. This may account in large part for some of the seemingly contradictory statements which are to be found in the literature, especially with respect to the influence of potassium and magnesium on boron accumulation. The present study was conducted in such a way that not only individual effects could be examined but so that interrelationships between calcium, magnesium, potassium, and boron supply and accumulation could be studied as well.

EXPERIMENTAL MATERIALS AND METHODS

Sand Cultures.—One-year-old budded Rome Beauty apple trees secured from a commercial nursery were used in the work. The trees were selected in the nursery row for uniformity of size and appearance. One hundred and eight dormant trees were planted out of doors on May 19, 1949 in five gallon glazed earthenware pots containing approximately 50 pounds of white silica sand. The tree roots were washed free of soil before planting. After growth had started all trees were pruned to leave seven lateral branches. Watering was accomplished twice daily by sub-irrigation. Five gallon soft glass bottles were used as solution reservoirs. Each of these reservoirs served to irrigate three adjacent pots containing one tree each. Rain water collected in a concrete cistern was utilized throughout the experiment for watering and for making nutrient solutions. Aluminum foil covers were fitted over the tops of the pots to guard against various sources of contamination. A general view of the experiment setup is shown in Figure 1.

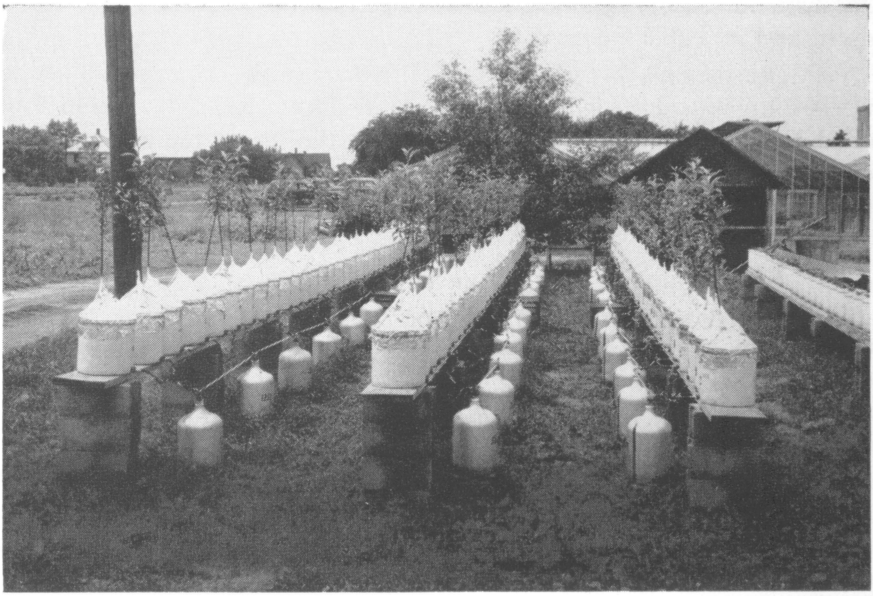


Fig. 1.—A general view of the experimental setup showing the nutrient solution reservoir bottles with pots on benches above so that after sub-irrigation the solutions return to the reservoirs by gravity. Three individual air pumps located at the middle of each row of trees and operated by a single time clock provided the air supply for pumping solutions. The row of trees on the left side received low calcium, those in the middle intermediate calcium, and those on the right high calcium. Varying combinations of magnesium, potassium, and boron supply were situated within each row. Aluminum foil covers over the pots were used to avoid contamination.

The trees were maintained on water until June 9, 1949 when differential treatments were begun. Thirty-six treatments were used involving 3 levels of calcium supply, 2 levels of magnesium supply, 2 levels of potassium supply and 3 levels of boron supply in all possible combinations. Other essential plant elements were supplied at constant levels. Each treatment was replicated 3 times.

Nutrient Solutions.—The composition of the nutrient solutions is shown in Table 1. Stock solutions of the indicated molarity were prepared in each case and from these the designated amounts were taken to make each liter of nutrient solution. Iron was supplied by mixing one tablespoon of magnetite into the top 3 inches of sand in each pot. The concentrations of the various elements in ppm comprising each of the 36 nutrient solutions and the initial pH values of each solution are given also in Table 1.

Measurements of pH and specific conductance were made at weekly intervals during June and July, 1949 in order to determine how often the solutions need be changed. On the basis of these measurements all solutions were renewed every 3 weeks during the growing season. Decreases in solution volume between changes were made up by adding water to the reservoirs every 2 or 3 days as necessary.

Foliage Sampling and Measurement of Growth.—On September 16, 1949, leaf samples were taken for chemical analysis. The samples consisted of 30 leaves per tree selected from the middle portion of current season's terminal growth. On the same date measurements were made of total terminal growth per tree. By October 16th the remaining foliage had fallen and the trees, still in the pots, were moved into a common cold storage for the winter months. During this period the pots were flushed thoroughly with water each week.

On April 20, 1950, the trees were removed from storage and the experiment again set up as in the previous season. Differential treatments were begun May 12, 1950, and continued until July 28th at which time all foliage was removed for chemical analysis and measurements of terminal growth were made. Trees which received a given treatment in 1949 received the same treatment in 1950.

Foliage samples collected each season were handled in a similar manner. Leaves were dried at 70° C. and then ground to pass the 40 mesh sieve in a Wiley mill. The dried, ground samples were stored in tightly capped glass bottles prior to analysis.

Although there was a difference of fifty calendar days between the 1949 and 1950 sampling dates the actual time difference during which the trees underwent differential treatment was only twenty days.

Chemical Analysis.—Total calcium, magnesium, and potassium were determined on one gram aliquots of each sample by flame photometric techniques following the general procedure described by Brown and Lilleland (10). Total nitrogen was determined by the Kjeldahl-Gunning official method (3). Boron was determined by using the quinalizarin-suluric acid method of Berger and Truog (6). All results are expressed on a dry weight basis.

Statistical Methods.—The data on boron content of the foliage were analyzed by analysis of variance according to the method of Snedecor (21). First the data for each year were analyzed separately to ascertain the significance of each of the individual effects and the interactions upon boron accumulation. Finally, data for both 1949 and 1950 were amassed, and the significance of differences resulting from individual and all interaction effects were determined.

The data on length of shoot growth were analyzed for variance to determine the significance of differences resulting from supplying different amounts of calcium, potassium, magnesium, and boron in the nutrient substrate.

RESULTS

Effect of Varying Proportions of Ammonium and Nitrate Ion in the Substrate on Foliage Accumulation of Boron, Nitrogen, Calcium, Magnesium, and Potassium.—The nutrient solutions employed were prepared to provide constant levels of all of the essential elements not under study. These solutions were also of nearly the same molar concentration and pH. In so doing, the amount of nitrogen supplied as the ammonium ion was varied from 0 to 48 percent of the total nitrogen. Ammonium nitrogen also varied inversely with the supply of each of the major cations as well as with the sum of the cations. In order to evaluate the possible effect of such variations in the proportion of ammonium to nitrate nitrogen the results of foliage analysis for boron, nitrogen, calcium, magnesium, and potassium are presented in Table 2. These data are arranged in order of decreasing ratios of ammonium to nitrate nitrogen in the substrate. Differential boron treatment has been disregarded because the ratio of ammonium to nitrate ion remained constant in a given calcium, magnesium, potassium series while boron was varied. Examination of the data for boron and nitrogen and for the major cations presented in Table 2 does not reveal any association between the ratio of ammonium to nitrate nitrogen in the substrate and the foliage concentration of these nutrients with the possible exception of calcium. In this particular case, the composition of the solutions

TABLE 1.—Composition of nutrient solutions showing milliliters of stock solution of given molarity to make 1 liter of nutrient solution† and pH

Culture No.*	$CaCl_2 \cdot 2H_2O$ 0.100M	$Ca(NO_3)_2 \cdot 4H_2O$ 0.1482M	$MgSO_4 \cdot 7H_2O$ 0.1000M	$Mg(NO_3)_2 \cdot 6H_2O$ 0.1000M	KH_2PO_4 0.0333M	K_2HPO_4 0.033M	KNO_3 0.2000M	NH_4NO_3 0.1424M	H_3BO_3 0.0469M	pH
1111	5 ml	None	5 ml	None	2.5 ml	2.5 ml	2.5 ml	54 ml	None	6.95
1112	"	"	"	"	"	"	"	"	1 ml	6.95
1113	"	"	"	"	"	"	"	"	10 ml	7.05
1121	'	"	"	'		"	20 ml	42 ml	None	6.95
1122	"	"	"	"		"	"	"	1 ml	6.90
1123	"	"	"	"	"	"	"	"	10 ml	7.05
1211	"	"	"	20 ml	"	"	2.5 ml	40 ml	None	6.90
1212	"	"	"	"	"	"	"	"	1 ml	6.95
1213	"	"	"	"	"	"	"	"	10 ml	6.90
1221	"	"	"	"	"	"	20 ml	28 ml	None	7.00
1222	"	"	"	"	"	"	"	"	1 ml	6.90
1223	"	"	'	"	"	"	"	"	10 ml	6.95
2111	"	6.6 ml	"	None	'	"	2.5 ml	47 ml	None	7.00
2112	"	"	"	"	"	"	"	"	1 ml	6.95
2113	"	"	"	"	"	"	"	"	10 ml	6.90
2121	"	"	"	"	"	"	20 ml	35 ml	None	7.00
2122	"	"	"	'	"	"	"	"	1 ml	6 95
2123	"	"	"		"	"	"	"	10 ml	7.00

2211	"	"	"	20 ml	"	"	2.5 ml	33 ml	None	6.95
2212	"	"	"	"	"	"	"	"	1 ml	6.95
2213	"	"	"	"	"	"	"	"	10 ml	6.95
2221	"	"	"	"	"	"	20 ml	21 ml	None	6.95
2222	"	"	"	"	"	"	"	"	1 ml	7.00
2223	"	"	"	"	"	"	"	"	10 ml	7.05
3111	"	26.5 ml	"	None	"	"	2.5 ml	26 ml	None	7.05
3112	"	"	"	"	"	"	"	"	1 ml	6.95
3113	"	"	"	"	"	"	"	"	10 ml	6.95
3121	"	"	"	"	"	"	20 ml	14 ml	None	7.00
3122	"	"	"	"	"	"	"	"	1 ml	6.95
3123	"	"	"	"	"	"	"	"	10 ml	7.00
3211	"	"	"	20 ml	"	"	2.5 ml	12.2 ml	None	7.00
3212	"	"	"	"	"	"	"	"	1 ml	7.00
3213	"	"	"	"	"	"	"	"	10 ml	7.05
3221	"	"	"	"	"	"	20 ml	None	None	7.05
3222	"	"	"	"	"	"	"	"	1 ml	6.95
3223	"	"	"	"	"	"	"	"	10 ml	7.00

*Numerical culture designations refer to levels of Ca, Mg, K and B in culture solutions respectively. Ca 1 = 20 ppm; Ca 2 = 60 ppm; Ca 3 = 180 ppm; Mg 1 = 12 ppm; Mg 2 = 60 ppm; K 1 = 30 ppm; K 2 = 166 ppm; B 1 = 0 ppm; B 2 = 0.5 ppm; B 3 = 5.0 ppm; Thus culture 1111 = 20 ppm Ca, 12 ppm Mg, 30 ppm K and O ppm B.

†Mn, Zn and Cu provided by adding 1 ml stock solution per liter of nutrient solution containing 10 gms/liter $MnSo_4 \cdot 4H_2O$, 4.5 gms/liter, $ZnSO_4 \cdot 7H_2O$, and 2.0 gms/liter $CuSO_4 \cdot 5H_2O$. Final conc. 2.5 ppm Mn, 1.0 ppm Zn, 0.5 ppm Cu.

N, P. S held at constant level of supply. Total conc. 224 ppm N, 5.2 ppm P, 16 ppm S.

was such that as the level of calcium was increased the percentage nitrogen as ammonium ion decreased. The author is of the opinion, therefore, that variations in the ammonium-nitrate nitrogen ratio of the nutrient solutions had no readily observable effect on the accumulation of the elements under study and was of little significance generally in the interpretation of the results.

Effect of Different Levels of Supply on the Foliage Contents of Calcium, Magnesium, Potassium, and Boron.—The results of foliar analyses for calcium, magnesium, potassium, and boron at each level of supply are summarized in Table 3, and appear in detail in Table 1 of the Appendix. As shown in Table 3, the calcium, potassium, and boron content of the trees was higher in 1949 than in 1950 while the reverse was true for magnesium. Nevertheless, in both years the differential levels of supply of a given element were effective in establishing different levels of that particular element in the foliage. These differences were statistically significant at the one percent level in 1949 and again in 1950.

With respect to the influence of these ions upon the accumulation of other ions the statistical analysis showed:

1) The foliage contents of calcium were influenced by calcium supply only.

2) The foliage contents of magnesium were affected directly by magnesium supply and inversely by the calcium supply.

3) The foliage contents of potassium were affected directly by potassium supply, directly by the calcium and boron supply in 1950, and inversely by the calcium and magnesium supply in 1949.

4) The foliage contents of boron were affected directly by the boron supply, directly by the calcium and magnesium supply in 1950, and inversely by the magnesium supply in 1949.

The calcium values in Table 3 are below the limiting value of 0.72 percent of the dry weight proposed by Wallace (22) except at the 180 ppm level of supply in 1949. The average leaf contents of magnesium in 1949 were below the 0.20 percent level cited in the literature as the critical concentration for this element in apple foliage (7, 13, 22). In 1950 the magnesium content of the foliage was above the 0.20 percent level at both levels of magnesium supply. Foliage contents of potassium were above the critical level of 1.00 percent of the dry weight (4, 19) in 1949 at both levels of potassium supply and in 1950 at the 166 ppm level of potassium supply only.

TABLE 2.—The influence of the ratio of ammonium to nitrate nitrogen in the nutrient solutions on the accumulation of boron, nitrogen, calcium, magnesium, and potassium by apple foliage

Culture No.*	% N as NH_4 in subst.	Foliage concentration—Dry weight basis									
		ppm Boron		% Nitrogen		% Calcium		% Magnesium		% Potassium	
		1949	1950	1949	1950	1949	1950	1949	1950	1949	1950
111x	48	78.4	23.0	2.61	2.30	0.60	0.27	0.117	0.262	2.00	0.93
211x	42	79.7	28.7	2.91	2.51	0.48	0.41	0.166	0.193	2.13	0.67
112x	37	62.8	36.2	2.59	2.48	0.34	0.31	0.121	0.364	2.64	1.69
121x	36	46.6	55.1	2.82	2.53	0.39	0.31	0.271	0.498	1.76	1.04
212x	31	78.0	19.5	2.97	2.62	0.43	0.41	0.152	0.213	2.57	1.55
221x	29	63.1	78.6	2.74	2.52	0.37	0.33	0.167	0.304	1.39	0.77
122x	25	73.1	41.4	2.78	2.45	0.40	0.25	0.251	0.279	2.05	1.31
311x	23	61.9	55.2	2.67	2.51	0.97	0.53	0.126	0.166	1.53	0.81
222x	19	58.9	43.9	2.70	2.34	0.46	0.36	0.134	0.295	1.69	1.68
312x	12.5	79.6	42.9	2.61	2.20	1.01	0.42	0.089	0.292	2.31	1.85
321x	11	81.7	66.7	2.47	2.22	0.97	0.56	0.138	0.369	1.32	0.96
322x	0	68.8	72.3	2.47	2.34	1.09	0.78	0.201	0.288	2.26	2.01

*Numerical treatment designations refer to levels of Ca, Mg, and K in the culture solutions respectively as described in footnote to Table 1. The designation x means that values given in the table represent averages of all levels of boron supply.

TABLE 3.—The average foliage contents of calcium, magnesium, potassium, and boron resulting from different levels of supply of these elements

Calcium			Magnesium			Potassium			Boron		
Supply in substrate ppm	Foliage content % of dry weight		Supply in substrate ppm	Foliage content % of dry weight		Supply in substrate ppm	Foliage content % of dry weight		Supply in substrate ppm	Foliage content ppm of dry weight	
	1949	1950		1949	1950		1949	1950		1949	1950
20	0.43	0.28	12	0.129	0.243	30	1.69	0.86	0	50.6	34.0
60	0 44	0.37	60	0.188	0.338	166	2.25	1.68	0.5	57.9	39.4
180	1.01	0.57							5 0	99.7	61.0
L.S.D.											
5 percent	0.15	0.09		0.016	0.039		0.10	0.11		9.7	12.9
1 percent	0 19	0.12		0.021	0.052		0.14	0.15		10 2	13.6

According to the above stated critical levels these data indicate that nutrient deficiencies occurred as follows:

1. Calcium at all levels of supply except 180 ppm in 1949
2. Magnesium at all levels of supply in 1949
3. Potassium at 30 ppm level of supply in 1950

Effect of Boron Supply on the Boron Content of the Foliage.—The results of foliar analysis for boron at different levels of boron supply are summarized in Table 3 and are presented graphically in Figure 2. Each value represents the mean of three replications of twelve treatments so that these values show the effect of level of boron supply only.

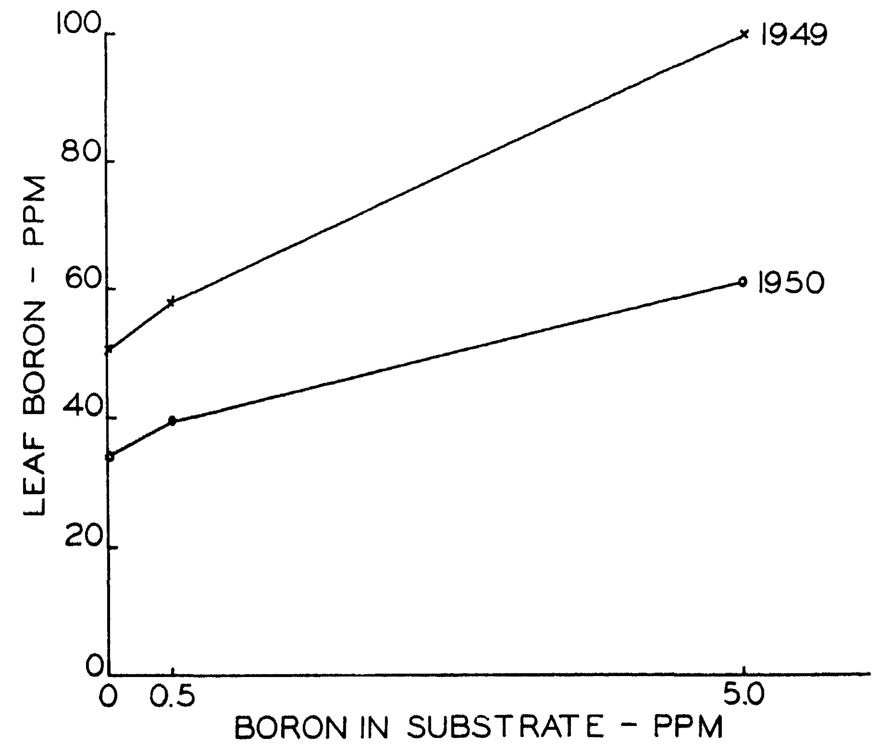


Fig. 2.—The effect of differential levels of boron in the nutrient substrate upon the concentration of boron in the leaves of young Rome Beauty apple trees.

In 1949, the average boron content of leaves varied from 50.6 to 99.7 ppm with the boron supply in the nutrient solution varying from 0 to 5.0 ppm. In 1950, the average boron content of the leaves varied from 34.0 to 61.0 ppm over the same range of boron supply (Table 3 and Figure 2). Boron in the foliage of *individual* treatment trees varied from a low of 8.2 ppm (Treatment 2121-1950) to 133.2 ppm (Treatment 3213-1949) as may be seen in Table 1 of the Appendix. Despite these wide variations in the boron content of the foliage, visual symptoms of neither boron deficiency nor boron toxicity were apparent at any time during the course of the experiment.

The data presented in Table 3 show that although increasing the supply of boron resulted in higher leaf contents of boron, the accumulation was greatest per unit of boron supplied at the 0.5 ppm level of supply. This is also apparent from the slope of the lines in Figure 2.

Differences in boron content of the foliage from the different treatments were significant at the 1 percent level each year.

Effect of Differential Calcium and Calcium-Boron Supply on Foliage Contents of Boron.—Differences in leaf contents of boron resulting from differential calcium supply were such that as the calcium supply increased boron in the foliage also increased (Table 4). These differences were not statistically significant in 1949 but were significant at the 1 percent level in 1950 between 20 and 180 ppm calcium supply and between 60 and 180 ppm calcium supply. These data indicate

TABLE 4.—The effect of differential calcium supply on the average foliage content of boron

Calcium in substrate as ppm	Boron in foliage as ppm—dry weight	
	1949	**1950**
20	65.2	38.9
60	69.9	42 7
180	73.1	52.9

L.S.D. 1949		L.S.D. 1950	
5 percent	N.S.	5 percent	6.2
1 percent	N.S.	1 percent	8 3

that only at high calcium levels of supply was the accumulation of boron affected to any great extent. This occurred only in 1950 when, by comparison with the previous year, both the boron and calcium concentrations in the leaves were low.

The combined effect of differential calcium and boron supply on boron accumulation is shown by the data presented in Table 5. Here it may be seen that only at 5.0 ppm boron supply was there a significant effect of differential calcium on the boron content of the foliage. In 1949 this difference was significant at the 5 percent level between 20 and 180 ppm calcium supply. The following year it was significant at the 1 percent level 20 and 180 and between 60 and 180 ppm calcium supply, but not significant between 20 and 60 ppm calcium supply.

At each level of calcium supply (Table 5) there occurred significant differences (at the 1 percent level) in boron content of the foliage between 0 and 5.0 ppm and between 0.5 and 5.0 ppm boron supply both years. In 1950 there were also significant differences at the 5 percent level between 0 and 0.5 ppm boron supply at 20 and 180 ppm calcium supply. Again it is apparent that the greatest effect from calcium was experienced in 1950 when the boron and calcium concentrations in the leaves were relatively low. It should be pointed out, however, that the effect of calcium was secondary to that of differential boron supply.

The relationship between boron and calcium supply and the accumulation of boron was positive and the interaction between boron and calcium was not significant, under the conditions of this experiment.

TABLE 5.—The average foliage content of boron resulting from different levels of supply of calcium and boron

Calcium in substrate as ppm	Boron in substrate as ppm					
	0	0.5	5.0	0	0.5	5.0
	Boron in foliage as ppm—dry weight					
		1949			1950	
20	45.0	59.3	91.4	31.4	34.6	50.7
60	51 9	58.0	99 8	30.0	40 1	57.8
180	54.9	56 3	108.0	40.3	43.5	74.4

LSD 1949		L.S.D. 1950	
5 percent	15.3	5 percent	11.1
1 percent	20 3	1 percent	14.3

Effect of Differential Magnesium and Magnesium-Boron Supply on Foliage Contents of Boron.—Differences in leaf contents of boron resulting from differential magnesium supply were such that as the magnesium supply increased foliage boron decreased in 1949, and increased in 1950 (Table 6). The difference in 1949 was significant at the 5 percent level and in 1950 at the 1 percent level. As was pointed out earlier from the data in Table 3, the average magnesium content of the foliage from both levels of magnesium supply in 1949 was below the accepted critical concentration. Under this magnesium deficiency condition high magnesium in the nutrient solution appears to have had a depressing effect on the accumulation of boron in the foliage. In contract to this, when magnesium in the foliage was above 0.20 percent of the dry weight at both levels of magnesium supply (Table 3), as was the case in 1950, high magnesium was associated with increased accumulation of boron (Table 6).

The combined effects of differential magnesium and boron supply on boron accumulation are shown by the data presented in Table 7. In 1949, magnesium supply level did not have a significant effect on boron accumulation in the foliage. The following year, however, high magnesium supply was associated with high foliage contents of boron at each of the three levels of boron supply and these differences were significant at the 1 percent level.

At each level of magnesium supply and in both years (Table 7) significant increases in the boron content of the foliage occurred as the boron supply level was increased from 0.5 to 5.0 ppm. These differences were significant at the 1 percent level. As with calcium, magnesium was secondary in importance to boron in affecting the foliage accumulation of boron.

TABLE 6.—The effect of differential magnesium supply on the average foliage content of boron

Magnesium in substrate as ppm	Boron in foliage as ppm—dry weight	
	1949	1950
12	73.4	34.2
60	65.4	55.4

L.S.D. 1949		L.S.D. 1950	
5 percent	7.2	5 percent	5.1
1 percent	N.S.	1 percent	6.7

TABLE 7.—The average foliage content of boron resulting from different levels of supply of magnesium and boron

Magnesium in substrate as ppm	Boron in substrate as ppm					
	0	0.5	5.0	0	0.5	5.0
	Boron in foliage as ppm—dry weight					
		1949			1950	
12	52.1	59.7	105.0	27.4	30.3	45.0
60	49.1	52.7	94.4	40.9	48.6	77.0

L.S.D. 1949		L.S.D. 1950	
5 percent	12.5	5 percent	9.1
1 percent	16.6	1 percent	11.7

Effect of Differential Potassium and Potassium-Boron Supply on Foliage Contents of Boron.—The two levels of potassium supply employed in this experiment did not have a significant effect on boron accumulation by the foliage. This is shown to be the case when differential potassium only is considered (Table 8) as well as when differential potassium at each of the three supply levels of boron is considered (Table 9).

At each of the two levels of potassium supply (Table 9) significant increases in the foliage content of boron occurred between 0 and 5.0 ppm boron supply and between 0.5 and 5.0 ppm boron supply. The differences were significant at the 1 percent level both years.

TABLE 8.—The effect of differential potassium supply on the average foliage content of boron

Potassium in substrate as ppm	Boron in foliage as ppm—dry weight	
	1949	1950
30	68.6	46.9
166	70.2	42.7

L.S.D. 1949		L.S.D. 1950	
5 percent	N.S.	5 percent	N.S.
1 percent	N.S.	1 percent	N.S.

TABLE 9.—The average foliage content of boron resulting from different levels of supply of potassium and boron

Potassium in substrate as ppm	Boron in substrate as ppm					
	0	0.5	5.0	0	0.5	5.0
	Born in foliage as ppm—dry weight					
	1949			1950		
30	50.2	58.5	97.1	35.9	40.0	65.0
166	47.6	57.3	102.4	32.1	38.9	57.0

L.S.D. 1949		L.S.D. 1950	
5 percent	12.5	5 percent	9.1
1 percent	16.6	1 percent	11.7

Effect of Differential Calcium-Magnesium Supply on Foliage Contents of Boron.—In 1949 the interaction between calcium and magnesium supply levels on boron accumulation was significant at the 5 percent level. As may be seen in Table 10, boron accumulation was unaffected by calcium when magnesium was supplied at 12 ppm. At 60 ppm magnesium supply, the foliage contents of boron increased as the calcium supply increased from 20 to 60 and finally to 180 ppm. This difference was significant at the 5 percent level. In 1950, the highest boron content obtained at 60 ppm magnesium and 60 ppm calcium supply levels, while at the low magnesium supply level leaf boron was highest under 180 ppm calcium supply. The interaction was significant at the 1 percent level.

TABLE 10.—The average foliage content of boron resulting from different levels of supply of calcium and magnesium

Magnesium in substrate as ppm	Calcium in substrate as ppm					
	20	60	180	20	60	180
	Boron in foliage as ppm—dry weight					
	1949			1950		
12	70.6	78.8	70.8	29.9	24.1	49.0
60	59.8	61.0	75.4	48.2	62.4	56.7

L.S.D. 1949		L.S.D. 1950	
5 percent	12.5	5 percent	9.1
1 percent	16.6	1 percent	11.7

Effect of Differential Calcium-Potassium Supply on Foliage Contents of Boron.—The influence of differential calcium-potassium supply levels on boron accumulation in 1949 was not significant (Table 11). The following year, however, the interaction between calcium and potassium supply levels was highly significant. At low potassium supply (30 ppm) leaf boron increased as the calcium level was raised from 20 to 60 ppm, but showed no significant change when calcium was further increased to 180 ppm. Conversely, at high potassium supply (166 ppm) leaf boron showed no significant change as calcium was increased from 20 to 60 ppm, but then increased greatly as calcium was further increased to 180 ppm. This occurred in a year when calcium was believed to be deficient at all supply levels and when potassium was deficient at the 30 ppm supply level (Table 3).

Effect of Differential Potassium-Magnesium Supply on Foliage Contents of Boron.—These data (Table 12) verify what has been shown previously; that potassium alone had no significant effect on boron accumulation, and that low magnesium favored boron accumulation in 1949 while high magnesium favored boron accumulation in 1950. The interaction between potassium and magnesium on boron content of the foliage was not significant.

Effect of Differential Calcium-Magnesium-Boron Supply on Foliage Contents of Boron.—In 1949 there was not a significant interaction between calcium, magnesium, and boron supply and boron content of the foliage. That is to say that the single ion effects shown to occur in

TABLE 11.—The average foliage content of boron resulting from different levels of supply of calcium and potassium

Potassium in substrate as ppm	Calcium in substrate as ppm: 20	60	180	20	60	180
	Boron in foliage as ppm—dry weight					
		1949			1950	
30	62.5	71.4	71.9	39.0	53.7	48.1
166	68.0	68.4	74.2	38.7	31.7	57.6

L.S.D. 1949
5 percent .... N.S.
1 percent .... N.S.

L.S.D. 1950
5 percent 9.1
1 percent 11.7

TABLE 12.—The average foliage content of boron resulting from different levels of supply of magnesium and potassium

Potassium in substrate as ppm	Magnesium in substrate as ppm			
	12	60	12	60
	Boron in foliage as ppm—dry weight			
	1949		1950	
30	73.3	64.0	35.6	58.3
166	73.5	66.9	32.8	52.5

L.S.D. 1949
5 percent . . . . N.S.
1 percent . . . . N.S.

L.S.D. 1950
5 percent 7.2
1 percent 9.5

Tables 3, 4, and 6 also hold true when these three elements are considered at all possible combinations. In 1950 the interaction between calcium, magnesium, and boron on boron accumulation was significant at the 5 percent level. The interaction occurred at the 5.0 ppm boron supply level and its nature is shown by the data presented in Table 13. These data show at 12 ppm magnesium as the calcium supply increased from 20 to 60 ppm foliage boron decreased slightly, but as calcium further increased to 180 ppm foliage boron increased significantly. At 60 ppm magnesium supply, however, foliage boron increased significantly with the first increment of calcium but then decreased as calcium was raised to 180 ppm. Although the 1949 interaction was not statistically significant it is of interest to note that the same direction of change in foliage boron was found to occur at 12 ppm magnesium as occurred at 60 ppm magnesium in 1950.

TABLE 13.—The average foliage content of boron resulting from differential levels of supply of calcium and magnesium at 5.0 ppm boron supply in 1950

Magnesium in substrate as ppm	Calcium in substrate as ppm		
	20	60	180
	Boron in foliage as ppm—dry weight		
12	38.6	25.4	71.0
60	62.8	90.3	77.9

L.S.D.
5 percent 15.2
1 percent 20.2

Effect of Differential Calcium-Magnesium-Potassium Supply on Foliage Contents of Boron.—The data presented in Table 14 and in Figures 3 and 4 show that a highly significant interaction between calcium, magnesium, and potassium on boron accumulation occurred during both years of the experiment. Careful comparison of the data for the two years shows, however, that in 1949 the different calcium and potassium supply levels influenced boron accumulation at the low (or high) magnesium supply level in exactly the same manner as they did at the high (or low) magnesium supply level in 1950. For example, in 1949 with 30 ppm potassium and 60 ppm magnesium as the calcium increased from 20 to 60 and finally to 180 ppm boron accumulation increased significantly. In 1950 this same influence was to be found not at the 60 ppm magnesium supply level but at the 12 ppm magnesium supply level. Moreover, during the first year increasing the calcium supply level favored boron accumulation if potassium was low and magnesium high and conversely if potassium was high and magnesium was low. That same year when the supply levels of these elements were both either high or low additional calcium appears to have depressed boron accumulation. In contrast, during 1950 increasing the calcium supply level favored boron accumulation so long as magnesium and potassium were both present in either high or low levels of supply.

TABLE 14.—The average foliage content of boron resulting from differential levels of supply of calcium, magnesium, and potassium

Potassium in substrate as ppm	Calcium in substrate as ppm: 20		60		180	
	Magnesium in substrate as ppm: 12	60	12	60	12	60
			1949			
30	78.3	46.6	79.7	63.1	61.9	81.9
166	62.8	73.1	78.0	58.9	78.5	68.8
			1950			
30	22.9	55.1	28.7	78.6	55.2	41.1
166	36.2	41.4	19.5	43.8	42.9	72.3

L.S.D. 1949
5 percent 17.6
1 percent 23.4

L.S.D. 1950
5 percent 12.4
1 percent 16.5

Effect of Differential Calcium-Potassium-Boron Supply on Foliage Contents of Boron.—The interaction between calcium, potassium, and boron on boron accumulation was not significant in 1949. In other words, during that year each of these elements influenced boron accumulation in the manner which has already been pointed out for the individual elements. As the boron and calcium levels of supply were increased the boron content of the foliage increased. Potassium supply level had no significant effect on foliage boron. In 1950, however, there was a highly significant interaction between the levels of supply of these three elements and the content of boron in the foliage. This interaction was essentially the same as noted earlier regarding the effect of differential calcium-potassium supply on foliage boron wherein at low potassium supply leaf boron increased as the calcium level was raised

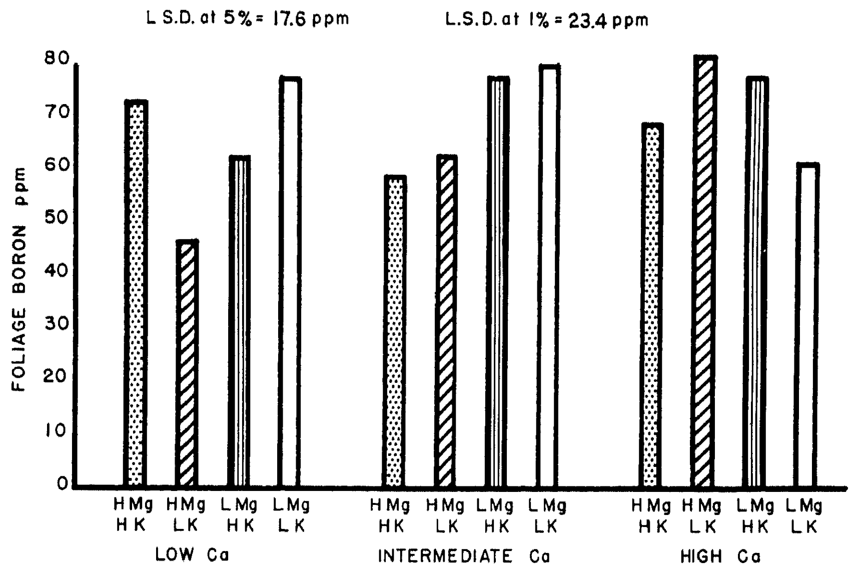


Fig. 3.—The effect of various combinations of calcium, magnesium, and potassium supply upon boron accumulation in the foliage of young Rome Beauty apple trees in 1949. Low, intermediate, and high calcium were 20, 60, and 180 ppm respectively. Low and high magnesium were 12 and 60 ppm respectively. Low and high potassium were 30 and 166 ppm respectively. Each bar of the graph is the average of nine trees including three replicates each of three levels of boron supply.

from 20 to 60 ppm but either decreased or remained unchanged as calcium was further increased to 180 ppm (Table 15). On the other hand at 166 ppm potassium supply leaf boron decreased slightly as calcium was increased from 20 to 60 ppm but then increased as calcium was increased to 180 ppm. The data also show (Table 15) that these effects were greatest at the 5.0 ppm boron level.

Effect of Differential Magnesium-Potassium-Boron Supply on Foliage Contents of Boron.—There was no significant effect of varying combinations of supply of magnesium, potassium, and boron on boron accumulation in 1949. Among the twelve combinations of treatments possible using these three variables, boron accumulation was greatest under conditions of low magnesium and high boron supply and was unaffected by potassium supply. The following year (1950-Table 16) the interaction of magnesium-potassium-boron on boron accumulation was significant at the 5 percent level. As may be seen in Table 16 potassium at 166 ppm significantly reduced the boron content of the

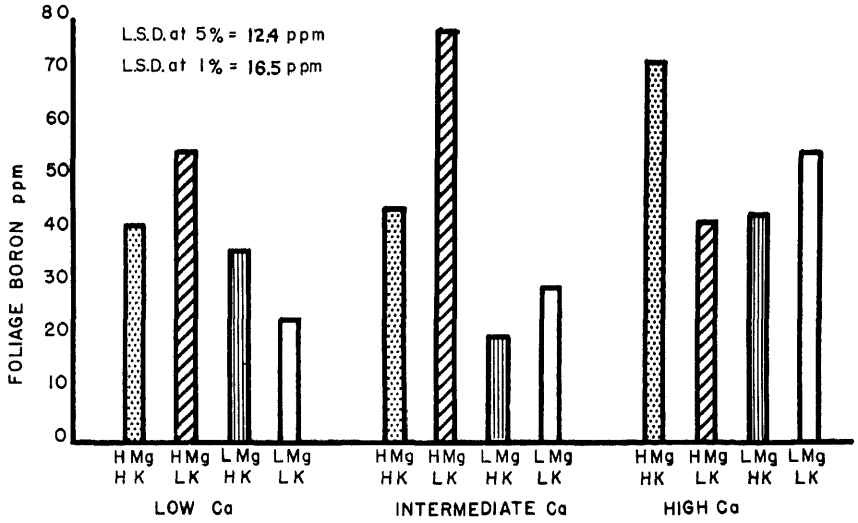


Fig. 4.—The effect of various combinations of calcium, magnesium, and potassium supply upon boron accumulation in the foliage of young Rome Beauty apple trees in 1950. Low, intermediate, and high calcium were 20, 60, and 180 ppm respectively. Low and high magnesium were 12 and 60 ppm respectively. Low and high potassium were 30 and 166 ppm respectively. Each bar of the graph is the average of nine samples including three replicates each of three levels of boron supply.

TABLE 15.—The average foliage content of boron resulting from differential levels of supply of calcium, potassium, and boron in 1950

Boron in substrate as ppm	Calcium in substrate as ppm: 20		60		180	
	Potassium in substrate as ppm: 30	166	30	166	30	166
0	33.0	29.7	35.9	24.1	38.7	42.5
0.5	28.6	40.6	48.2	32.1	43.1	44.0
5.0	55.4	46.0	76.9	38.8	62.6	86.3

L.S.D.
5 percent . 15.2
1 percent . 20.2

foliage at 60 ppm magnesium and 5.0 ppm boron over that obtained with 30 ppm potassium. The effect of high magnesium in increasing boron accumulation is apparent in every comparison of the data in Table 16. It will also be noted that with high magnesium (60 ppm) as the boron supply increased from 0 to 0.5 and finally to 5.0 ppm the boron content of the foliage also increased. With low magnesium (12 ppm), on the other hand, as the boron supply increased from 0 to 0.5 ppm there was no or very little increase in boron content while with further increase in boron supply to 5.0 ppm the boron content of the foliage increased markedly. This appears to be the same interaction

TABLE 16.—The average foliage content of boron resulting from differential levels of supply of magnesium, potassium, and boron in 1950

Potassium in substrate as ppm	Boron in substrate as ppm: 0		0.5		5.0	
	Magnesium in substrate as ppm: 12	60	12	60	12	60
30	35.7	45.0	35.7	54.3	48.8	97.5
166	25.9	46.3	32.4	55.1	52.5	75.8

L.S.D.
5 percent . . 12.4
1 percent 16.5

effect noted earlier regarding the results presented in Table 7. Even though the 1949 interaction of magnesium-potassium-boron was not significant it is of interest to note that the effects observed at 60 ppm magnesium in 1950 occurred with 12 ppm magnesium in 1949 and conversely those which occurred at 12 ppm magnesium in 1950 were observed at 60 ppm magnesium in 1949.

Effect of Different Levels of Supply of Calcium, Magnesium, Potassium, and Boron on Terminal Growth.—The data presented in Figure 5 show the growth response of young Rome Beauty apple trees to different levels of supply of boron, calcium, magnesium, and potassium. The data for average total growth by individual treatment trees appear in Table II of the Appendix. These figures represent the growth in centimeters per tree made by all of the terminal growing points on the tree.

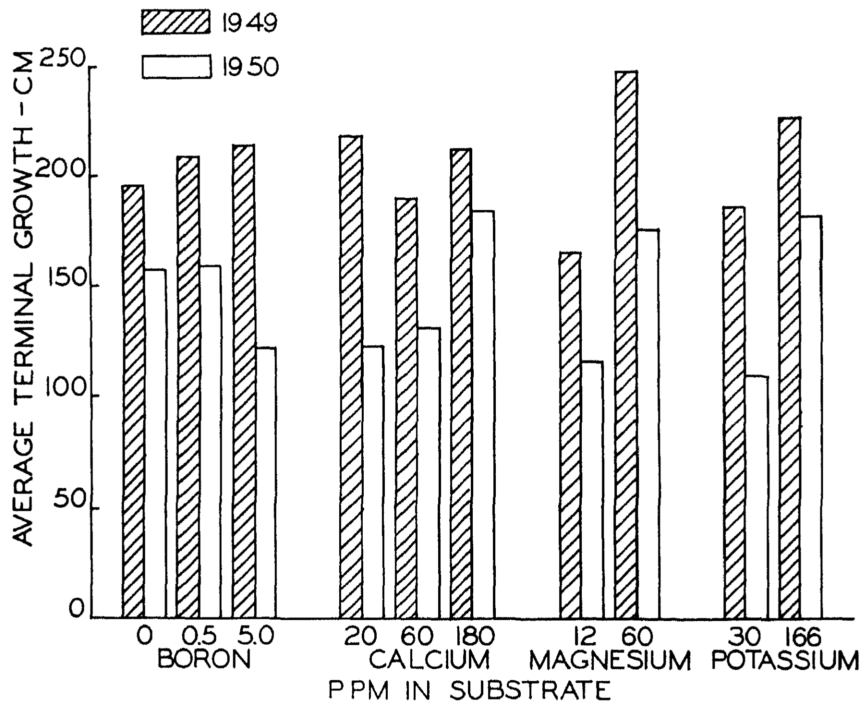


Fig. 5.—The effect of differential levels of boron, calcium, magnesium, and potassium in the nutrient substrate upon the terminal growth of young Rome Beauty apple trees.

The differences in terminal growth by trees which received different levels of boron supply were not statistically significant in either 1949 or 1950. Differences in growth resulting from different levels of calcium supply were not significant in 1949. In 1950, trees which received 180 ppm calcium made significantly more terminal growth than those which received either 20 or 60 ppm calcium. These differences were significant at the 1 percent level.

Both years trees receiving 60 ppm magnesium made greater terminal growth than those which received 12 ppm magnesium. Trees receiving 166 ppm potassium also made greater terminal growth than those which received 30 ppm. Differences in growth resulting from differential magnesium and differential potassium supply were significant at the one percent level both years.

The trees made only about 70 percent as much terminal growth in 1950 as they had made the previous year. This reduction in growth may have been due in part to the fact that boron, calcium, and potassium in the foliage were present in lower concentrations than during the previous year. In fact, calcium was below the critical concentration at all levels of supply and potassium was below the critical level at the 30 ppm level of supply (Table 3). The growth data (Figure 5) appear to bear this out since increasing calcium and potassium supply levels in 1950 resulted in larger and more regular increases in growth than they had the previous year.

DISCUSSION OF THE FACTORS AFFECTING BORON ACCUMULATION

The interpretation of the data is complicated by several factors. Among these was the number of individual treatments included in the work. Each year there were thirty-six individual treatments representing different levels of supply of calcium, magnesium, potassium, and boron. These give rise to a number of possible interaction effects, the significance of which must be examined to adequately interpret the data. In addition to the main effects of calcium, magnesium, potassium, and boron there were each year five first order interactions (boron × potassium, boron × magnesium, boron × calcium, calcium × magnesium, calcium × potassium), four second order interactions (calcium × boron × magnesium, calcium × magnesium × potassium, calcium × potassium × boron, and boron × magnesium × potassium), and finally one-third order interaction including all four variables. In the discussion which follows the writer has attempted to point out why certain of these interactions are significant, and the practical value or application that may be attached to the findings.

The interpretation is also complicated by the fact that the leaf contents of the various elements in question were greatly different during the two years of the experiment (Table 3). Calcium, potassium, and boron were present in lower concentrations in 1950 while magnesium was present in higher concentration in 1950. This implies that the trees themselves contained reserves of calcium, potassium, and boron so that their foliage contents during the first year of the experiment reflected not only the influence of differential treatment but in addition a quantity of each of these elements withdrawn from other tissues. Furthermore, assuming that equilibrium was reached during the second year, calcium at that time was not supplied in sufficient quantity to give leaf contents above the accepted critical concentration, magnesium was apparently adequate at both supply levels, and potassium was adequate at 166 ppm but deficient at 30 ppm supply levels (Table 3).

Finally, relatively high average foliage contents of boron were found when no boron was added to the nutrient solutions. This may have been due to a reserve supply of boron within the trees at the beginning of the experiment which was sufficient to prevent the occurrence of visual symptoms of boron deficiency during the first year. Even after one full season's growth, during which time this reserve supply of boron should have been depleted, enough boron was still supplied, possibly through contamination, to give average leaf contents higher than those considered critical. The stored rain water and impurities in the reagent grade chemicals used in making the nutrient solutions are regarded as the most likely sources of contamination.

It is unfortunate that it was not possible to continue the experiment for at least a third year in order to check the results obtained in 1949 and 1950. This seemed inadvisable at the time because of the crowding of the root systems of certain of the more vigorously growing trees. Certainly, in future work of this nature some technique should be employed to obtain trees which contain a minimum quantity of reserve nutrient elements, particularly those which are to be included as variables in the experiment. Regardless of the admitted shortcomings of the work, some effects appeared consistently enough to warrant the drawing of certain conclusions.

As would be expected, the level of boron supply was found to exert to the greatest and most consistent influence on foliage accumulation of boron. This was found to be the case not only when boron levels of supply were considered independently but also when varying levels of boron supply were associated with varying levels of calcium, magnesium, and potassium in all of their possible combinations. There can be little doubt that the boron content of the foliage was determined primarily by the amount of boron supplied to the tree.

Second in importance to boron supply was the supply of calcium. Although the differences in foliage boron in 1949 resulting from differential calcium treatment were not statistically significant, they were in the same direction as those obtained in 1950 when increasing the calcium supply was associated with increased accumulation of boron. These results are in substantial agreement with those of other workers (8, 9, 12, 14, 15, 18) and are believed to explain in part why boron deficiency occurs on over-limed or highly alkaline soils. Under such conditions of high calcium availability, plant foliage would accumulate greater total quantities of boron. At the same time the supply of available boron in the soil would probably be decreased due to the formation of insoluble boron compounds. Thus with a situation of more rapid withdrawal of available boron from the soil together with less available soil boron, symptoms of boron deficiency appear.

Following calcium, the results obtained in this work indicate that magnesium played an important part in boron accumulation. However, the influence of magnesium was shown to be positive one year and negative the other. In 1949, when trees of both magnesium treatments were considered magnesium deficient, high magnesium supply was associated with reduced boron accumulation. In 1950, however, with magnesium above the critical level at both rates of supply high magnesium was associated with increased boron accumulation.

Potassium supply, considered independently, did not have a significant influence on boron accumulation during either year of the experiment. This included a year when foliage potassium was above the critical level at both levels of potassium supply as well as a year when potassium was below the critical level at the 30 ppm supply level (Table 3).

In addition to single element effects, the results of this study show that the influence of calcium, magnesium, potassium, and even boron itself were interrelated. In certain instances the individual element effects were additive. Such was the case with boron and magnesium in 1949 as shown in Table 7. In other instances the effects were not additive and significant interactions between the several variables occurred. One of the best examples of such an interaction was that which occurred between calcium, magnesium, and potassium as they influenced the foliage accumulation of boron. The interesting thing about this particular interaction was that boron accumulation at different calcium and potassium supply levels was influenced at low magnesium levels of supply in 1949 in the same way that it was influenced by high magnesium in 1950. Conversely, high magnesium in 1949 affected boron accumulation in the same way as did low magnesium in 1950. The reason for this reversal in the effect of magnesium is not apparent but it is interesting to note that in 1949 when low magnesium was associated with high boron accumulation the magnesium content of the trees was relatively low while in 1950 when the high boron accumulation was associated with high magnesium the magnesium content of the trees was relatively high (Table 3).

The nature of the interaction between calcium, magnesium, and potassium on the accumulation of boron is illustrated graphically in Figures 6 and 7. Because boron accumulation took place in 1949 under low magnesium supply in the same manner as at high magnesium supply in 1950 these two figures are reversed in so far as magnesium is concerned. In 1949, the low magnesium levels of supply are placed on the rear side of the solid figure (Figure 6) while in 1950 the high magnesium supply levels occupy that same position (Figure 7). With the exception of this reversal in behavior regarding magnesium it may be seen by comparing these two figures that boron accumulation took place under differential calcium, magnesium, and potassium treatments the same way during both years. One segment of the interaction effect occurred in 1949 (Figure 6) at low magnesium-low potassium levels of supply when increasing the calcium level from 60 to 180 ppm resulted in a decrease in the boron content of the foliage. A second segment of the interaction occurred at high magnesium-high potassium levels of supply where boron in the foliage decreased as calcium was increased from 20 to 60 ppm but increased as calcium was further raised to 180 ppm. At low magnesium-high potassium as well as at high magnesium-low potassium supplies boron accumulation increased as a function of increasing calcium supply.

In 1950 (Figure 7), the same relationship were found to occur regarding calcium and potassium on boron accumulation but those which occurred with low magnesium in 1949 were associated with high magnesium in 1950 and conversely those which occurred with high magnesium in 1949 occurred with low magnesium in 1950.

Since the calcium-potassium influence was constant during both years of the experiment it seemed desirable to examine this relationship further from the standpoint of the quantities of these elements and magnesium in the plant foliage. This seemed particularly appropriate because the foregoing discussion was based primarily on rates of supply of these elements rather than on the quantities in the plant. Although in a general way one is indicative of the other exceptions did occur as shown by the data in Table 17. Such was the case for calcium and magnesium in 1949 and for magnesium in 1950. The data presented in Table 17 are expressed in milliequivalents per 100 grams of dry tissue in order that the three cations may be compared on a chemically equivalent basis. In an attempt to integrate the effect of more than a

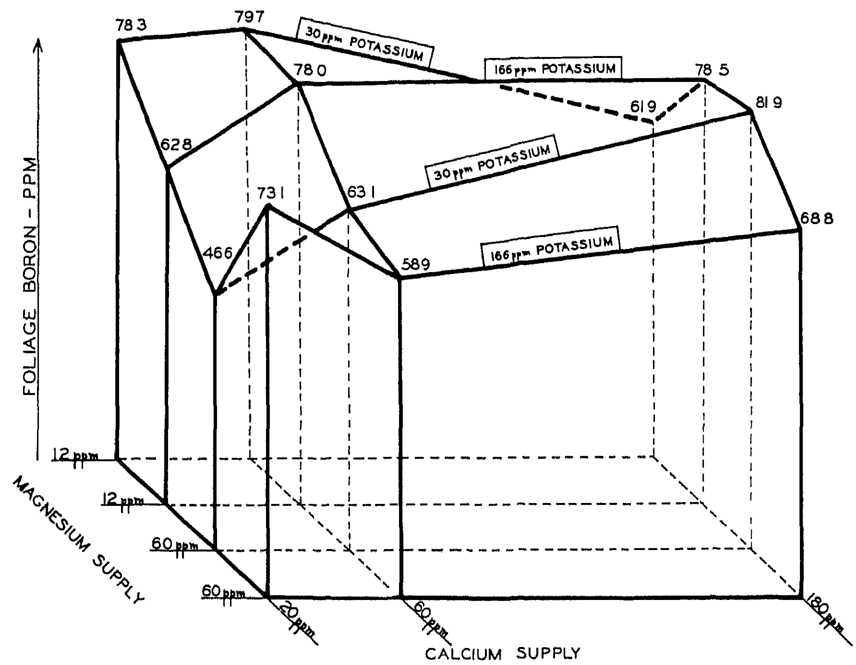


Fig. 6.—The effect of various combinations of calcium, magnesium, and potassium supply on boron accumulation in the foliage of young Rome Beauty apple trees in 1949. Attention is called to the fact that the *low* magnesium supply levels are located on the rear half on the solid figure because more boron was accumulated under low magnesium supply during 1949.

single variable, ratios of these three elements in the foliage have been calculated and examined as functions of boron accumulation. Of the numerous possible combinations of ratios so calculated and examined the potassium/calcium ratio was most clearly associated with boron accumulation. This association was evident, however, only when the two levels of magnesium supply were considered separately. The calcium plus magnesium/potassium ratio was also associated with boron accumulation as was reported by Shear, Crane and Meyer (20) but was not as clearly defined as was the association with the potassium/calcium ratio. To facilitate the interpretation of the potassium/calcium ratios, the ratio values for each combination of calcium, magnesium, and potassium treatment versus foliage boron are plotted graphically in

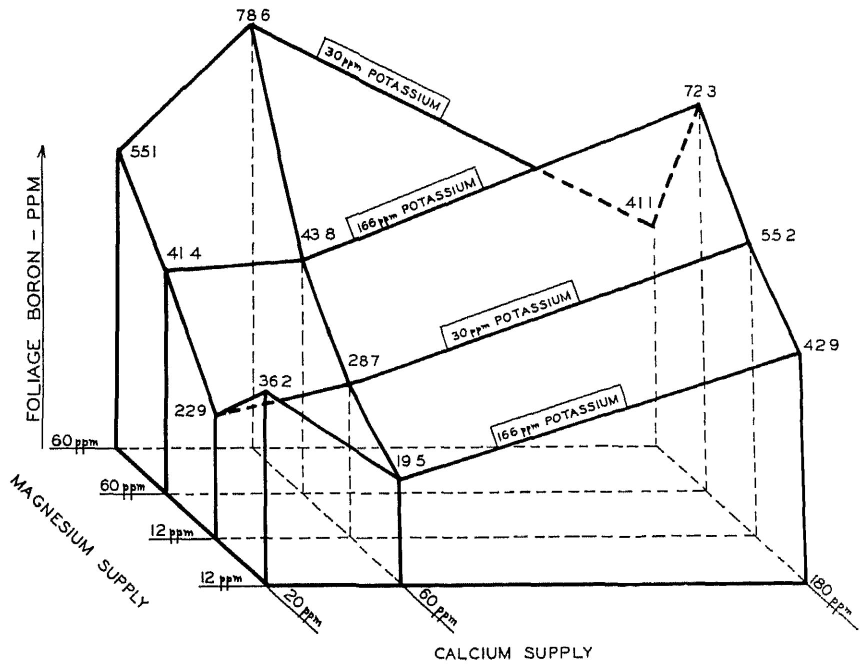


Fig. 7.—The effect of various combinations of calcium, magnesium, and potassium supply on boron accumulation in the foliage of young Rome Beauty apple trees in 1950. Attention is called to the fact that the *high* magnesium supply levels are located on the rear half of the solid figure because more boron was accumulated under high magnesium supply in 1950.

Figure 8 for 1949 and Figure 9 for 1950. Since the reversal of magnesium from low in 1949 to high in 1950 has been shown to influence boron accumulation, all values for the potassium/calcium ratio resulting from low magnesium are plotted separately from those resulting from high magnesium treatment. The continuous lines which resulted from joining all ratios occurring under low magnesium treatment as opposed to those occurring under high magnesium treatments provide a means for the selection of treatments which gave potassium/calcium ratios favorable to the accumulation of boron. In Figures 8 and 9 the mean boron concentration of the foliage is represented by a horizontal line which in each case bisects the potassium/calcium ratio "curves." The interpretation of the significance of the potassium/calcium ratio is based on the assumption that all boron values higher than the mean value are representative of treatments which favored high boron accumulation. In 1949 (Figure 8) under conditions of low magnesium supply, maximum accumulation of boron occurred within rather

TABLE 17.—The effect of various treatments involving different levels of calcium, magnesium, and potassium upon the foliage accumulation of these elements by young Rome Beauty apple trees grown in sand culture

Treatment No.*	1949			1950		
	Milli-equivalents per 100 grams of dry tissue					
	Ca	Mg	K	Ca	Mg	K
111X	30.0	9.6	51.3	13.5	21.5	23.8
112X	17 0	9.9	67.7	15 5	29.9	43.3
121X	19.5	19.6	45.1	15.5	40.9	26.7
122X	20.0	20.6	52.6	12.5	22.9	33.6
211X	24.0	13.6	54.6	20.5	15.9	17.2
212X	21.5	12.5	65.9	20 5	17.5	39.7
221X	18 5	13 7	35.9	16.5	25.0	19.7
222X	24.0	11.0	43.3	18.0	24.3	43.1
311X	48.5	10.7	39.2	26 5	13.6	20.8
312X	51.0	7 3	59.2	21.0	21.3	47.4
321X	48.5	11.3	33.8	28.0	30.3	24.6
322X	54.5	16.5	57.9	39.0	23.7	51.5

*Each value is the mean of nine determinations including three levels of boron (as represented by X in treatment number) and three replicates.

definite limits in potassium/calcium ratio values. These values were from 0.95 to 3.05 while with ratio values above or below these limits boron accumulation was below the mean value. In 1950 a similar curve was obtained employing potassium/calcium ratio values occurring under high magnesium treatment (Figure 9). In that year better than average boron accumulation was associated with ratio values ranging from 0.87 to 2.33.

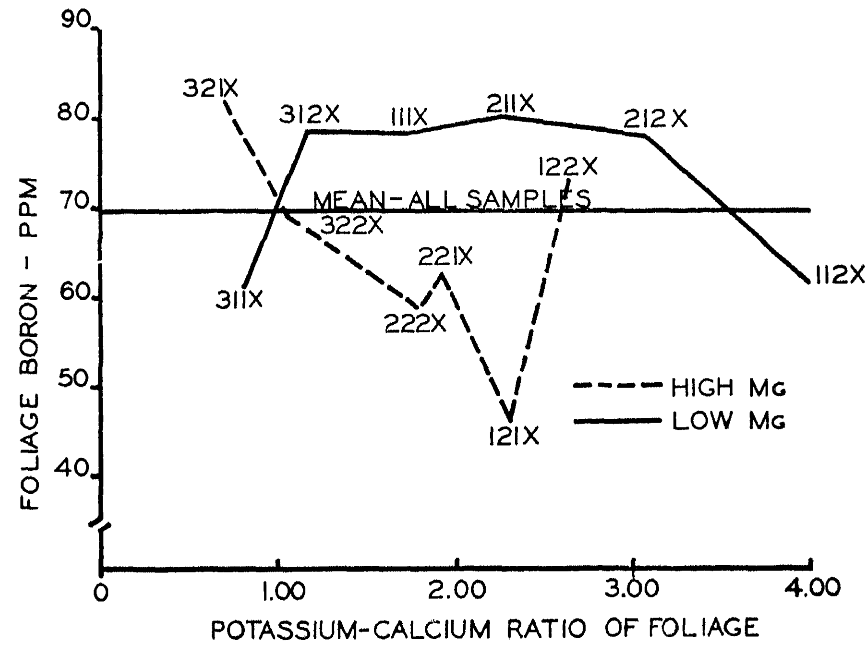


Fig. 8.—The ratio of milliequivalents of potassium to calcium in the foliage of young Rome Beauty apple trees grown in sand culture under differential levels of supply of calcium, magnesium, and potassium in 1949. Each point making up the curve is the average of nine samples and includes three levels of boron supply replicated three times. The numbered points on the curves represent the various combinations of calcium, magnesium, and potassium supply levels described in the footnote to Table 1.

Under high magnesium treatment in 1949 (Figure 8) and low magnesium treatment in 1950 (Figure 9) the "curves" for ratio of foliage potassium/calcium were such that maximum boron accumulation occurred on the extremes of these curves. Again, using the mean value as a criterion of boron accumulation, in 1949 under high magnesium treatment the greatest accumulation occurred with ratio values of less than 1.02 or greater than 2.62 (Figure 8). In 1950 under low magnesium treatment the highest accumulation of boron occurred when

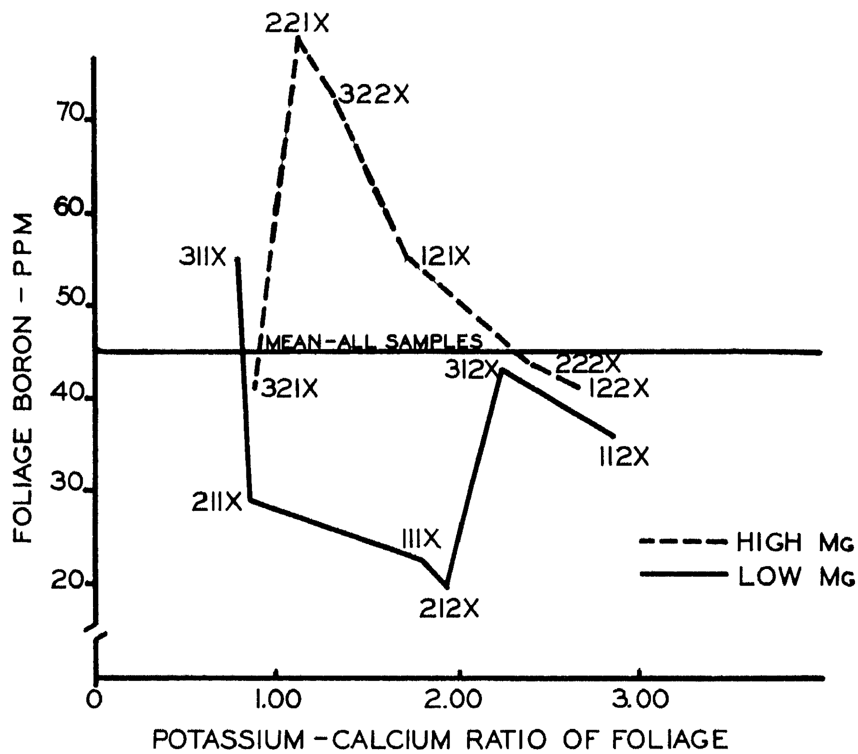


Fig. 9.—The ratio of milliequivalents of potassium to calcium in the foliage of young Rome Beauty apple trees grown in sand culture under differential levels of supply of calcium, magnesium, and potassium in 1950. Each point making up the curve is the average of nine samples and includes three levels of boron supply replicated three times. The numbered points on the curves represent the various combinations of calcium, magnesium, and potassium supply levels described in the footnote to Table 1.

the potassium/calcium ratio was less than 0.80. However at the highest ratio values occurring under this same set of conditions no foliage concentrations of boron exceeded the mean value for all samples although treatment number 312x closely approached it.

The fact that the 1950 potassium/calcium ratios favoring highest accumulation of boron were lower than those for 1949 may be due in part to the difference in the kind of foliage making up the samples. In 1950 all leaves were taken to make up the foliage sample whereas the previous year only medium shoot leaves were sampled. This meant that the 1950 leaf sample had a higher dry weight and a higher percentage of calcium because a large proportion of the sample was of older and more mature leaves which would result in lower potassium/calcium ratio values.

The author is of the opinion that the relationship of potassium to calcium in the foliage of these apple trees, as well as the supply levels of these elements, was of utmost importance in determining their capacity to absorb and accumulate boron. This relationship could only be shown, however, after the magnesium content of the trees and their magnesium supply level was established. Those trees whose foliage contained low amounts of magnesium (less than 0.20 percent of the dry weight) and which were supplied with 12 ppm magnesium and trees whose foliage contained in excess of 0.24 percent magnesium and which were supplied with 60 ppm magnesium accumulated maximum concentrations of boron when the potassium content of the foliage was from 0.9 to 2.5 times the calcium content of the foliage on a milliequivalent basis.

The results of the present study agree with previous findings (8, 9, 12, 14, 15, 18) regarding the effect of calcium on boron accumulation in that as the supply of calcium increased the accumulation of boron also increased. The findings with respect to magnesium and potassium do not agree with those of other investigators. The depressing effect of potassium noted by other workers (11, 20) was not evident under the levels of potassium employed in this work. The effect of magnesium noted by Shear, et al. (20), was found to exist in 1949 in the present experiment, but not the following year when magnesium levels of the trees were well above the accepted critical percentage. These discrepancies may be due in part to the different levels of nutrients employed and to differences in response between the apple and other species.

PRACTICAL APPLICATION OF THE FINDINGS

At the present time recommendations for the application of boron to apple trees are based upon the occurrence of visual symptoms of boron deficiency. When such symptoms occur growers are advised to apply borax at the rate of ¾ pound per mature bearing tree every third year. This application has been effective in correcting the visual symptoms of boron deficiency. In a few instances where chemical data have been made available and where the foliage content of median shoot leaves in late July was 20 ppm boron or less a similar recommendation was made even though no visual symptoms were in evidence. No doubt the practice of basing recommendations for boron application upon the occurrence of visual boron deficiency symptoms will continue until such time that diagnosis can be based on chemical analysis of the foliage. It should be recognized, however, that at some point before visual symptoms occur boron deficiency may have already caused a reduction in growth and yield.

The practical benefits to be derived from these results are associated with two general conclusions that have been drawn from the work. The first of these is that boron in the foliage of apple trees may vary over wide extremes in concentration without significantly affecting growth and without resulting in the development of visual symptoms of boron deficiency or boron toxicity. The second conclusion is that the supply of certain elements, principally calcium and magnesium, exerts a definite influence on the amount of boron accumulated in apple foliage. In the case of potassium, the influence is less pronounced. In fact, in the present work potassium alone did not influence boron accumulation and it was only when the potassium supply was varied along with varying supply levels of calcium and magnesium that a potassium effect on boron accumulation was demonstrated.

In attempting to apply the results of this study the assumption is made that apple trees growing under field conditions would respond to differential calcium, magnesium, potassium, and boron treatments in the same general manner as did young trees grown in sand culture and fertilized with nutrient solutions. Furthermore, it is assumed that field soil conditions which provide high or low quantities of available calcium, magnesium, potassium, or boron would result in the same response that was obtained when trees were grown in sand culture with varying amounts of these four elements supplied by means of nutrient solutions. Based on these assumptions the following situations are described to aid growers in arriving at a decision as to whether or not boron fertilizers should be applied:

1. Apple trees growing on soils known to contain high amounts of available calcium would tend to accumulate large quantities of boron in their foliage as well as in other vegetative parts of the tree. The relatively rapid withdrawal of boron from the soil under this situation is expected to result in an earlier occurrence of boron deficiency than would be the case under low soil calcium availability. Therefore, apple trees growing on soils which have been limed heavily or on soils which are naturally alkaline in nature are likely to require earlier and more frequent applications of borax.

2. Apple trees growing on soils which contain either high or extremely low quantities of available magnesium would tend to accumulate larger amounts of boron in their foliage and other plant parts. Under these conditions the greater rate of removal of available boron from the soil is expected to result in the earlier occurrence of boron deficiency by apple trees. Growers whose orchards are located on such soils are cautioned to observe carefully for the appearance of boron deficiency symptoms and to apply borax at the recommended rate as soon as a reduction in growth, dieback of terminal shoots and smaller branches, and external and internal cork symptoms on the fruit are observed. Those orchards where leaf magnesium is as low as 0.20 percent of the dry weight also should benefit from the application of magnesium fertilizers or dolomitic limestone. The latter should be applied only if a definite need for lime is indicated.

3. Judging by the influence of high calcium and high magnesium upon boron accumulation demonstrated in this work, the unwarranted use of lime on orchard soils should be avoided. No doubt there are many situations where lime is needed to benefit both tree and cover crop growth. On soils where available calcium and magnesium are low, where cover crop growth is sparse due to unfavorable soil reaction, and where deficiency symptoms of these elements are observed, lime should be applied. In light of the present findings, it would appear that applications of lime should be based on a reliable test of soil reaction plus chemical analysis of both the soil and apple tree foliage for calcium, magnesium, and boron rather than on the speculation that an application of lime every several years is a desirable practice.

At such time as it is possible for commercial growers to obtain data on the chemical composition of their apple foliage the present findings will have much wider application in making recommendations for boron application. When such data are at hand growers would be well advised to apply borax whenever the foliage content of mid-shoot leaves for boron is at 20 parts per million of the dry weight or less in late July. Also, orchards whose foliage is found to contain on the average as low as 0.13 percent magnesium (which represents magnesium deficiency) are expected to accumulate extremely large amounts of boron when the calcium-potassium ration of the foliage is between approximately 1 and 3. At the same time orchards whose foliage is found to contain as much as 0.36 percent magnesium are also expected to accumulate extremely large amounts of boron when the calcium-potassium ration in the foliage is between approximately 1 and 2.6. Under these situations with respect to magnesium, the rate of removal of boron from the soil would be such that an earlier occurrence of boron deficiency could be anticipated.

SUMMARY AND CONCLUSIONS

1. Young Rome Beauty apple trees were grown in sand culture during the 1949 and 1950 growing seasons under differential treatments involving three levels of supply each of calcium and boron and two levels of supply each of potassium and magnesium in order to study the influence of these variables upon boron accumulation and boron requirement. The thirty-six different treatments were replicated three times.

2. Foliage samples were taken each season for quantitative determinations of total nitrogen, calcium, magnesium, potassium, and boron.

3. Total terminal growth was measured following the formation of terminal buds each growing season.

4. The calcium, potassium, and boron content of the foliage was found by analysis to be relatively high in 1949 and low in 1950. Conversely, the magnesium content of the foliage was low in 1949 and high in 1950.

5. All differential treatments were, on the average, effective in establishing different levels of a given element in the foliage. In the case of some of the individual treatments, however, an increase in the substrate level of a given element did not result in increased foliage content of that element.

6. The 0.0, 0.5, and 5.0 ppm levels of boron supply were consistently associated with successive increases in foliage boron and these differences were of a high order of significance.

7. Maximum accumulation of boron occurred at the 12 ppm magnesium supply level in 1949 and at the 60 ppm magnesium supply level in 1950.

8. Potassium supply levels of 30 and 166 ppm did not have a significant influence on boron accumulation.

9. The influence of calcium supply levels of 20, 60, and 180 ppm was direct and positive both years. The differences were significant in 1950 only, however.

10. Increases in calcium, magnesium, and potassium supply levels were associated with significant increases in total terminal growth in 1949 and 1950. Increases in boron supply levels did not result in significant differences in terminal growth.

11. All trees made less terminal growth in 1950 than in the previous year. This was attributed largely to the lower foliage concentrations of calcium, potassium, and boron in 1950 which is believed to have resulted from restriction of the root systems during the second year of the experiment.

12. The interaction of calcium, magnesium, and potassium on boron accumulation was highly significant both years. The influence of calcium and potassium on boron accumulation was the same under low magnesium supply in 1949 as under high magnesium supply in 1950. Conversely, it was the same under high magnesium in 1949 as under low magnesium in 1950.

13. The author offers no explanation for the reversal in the influence of magnesium during the two years. Low magnesium was associated with high boron accumulation during the year when the magnesium content of the trees was low and high magnesium supply with high boron accumulation when the magnesium content of the trees was high, however.

14. When trees with low or high magnesium contents were supplied with low or high magnesium supply respectively, maximum boron accumulation occurred when the potassium/calcium ratio of the foliage ranged from approximately 0.9 to 2.5 on a milliequivalent basis.

15. The practical implications of the findings are discussed briefly.

LITERATURE CITED

1. Askew, H. O. 1935. The boron status of fruit and leaves in relation to "internal cork" of apples in the Nelson district. New Zealand Jour. Sci. Tech. 17: 388-391.

2. ———, and E. Chittenden. 1936. The use of borax in the control of "internal cork" of apples. Part II. The effect of tree injections of borax solutions on the boron status of apple trees. Jour. Pomol. and Hort. Sci. 14: 239-242.

3. Association of Official Agricultural Chemists. Methods of Analysis. 6th Edition. 1945. Washington, D. C.

4. Batjer, L. P., and J. R. Magness. 1939. Potassium content of leaves from commercial apple orchards. Proc. Amer. Soc. Hort. Sci. 36: 197-201.

5. Beattie, J. M., and C. W. Ellenwood. 1950. A survey of the nutrient status of Ohio apple trees. Proc. Amer. Soc. Hort. Sci. 55: 47-50.

6. Berger, K. C., and Emil Truog. 1943. Boron tests and determination for soils and plants. Soil Sci. 57: 25-36.

7. Boynton, D., and J. Van Geluwe. 1943. Incipient magnesium deficiency in some New York orchards. Proc. Amer. Soc. Hort. Sci. 42: 95-100.

8. Brenchley, W. E., and K. Warington. 1927. The role of boron in the growth of plants. Ann. Bot. 41: 167-187.

9. Brennan, E. G., and J. W. Shive. 1948. Effect of calcium and boron nutrition of the tomato on the relation between these elements in the tissues. Soil Sci. 66: 65-75.

10. Brown, J. G., O. Lilleland and R. K. Jackson. 1950. Further notes on the use of flame analysis of plant material for potassium, calcium, magnesium, and sodium. Proc. Amer. Soc. Hort. Sci. 56: 12-22.

11. Chapman, H. D., and S. M. Brown. 1943. Potash in relation to citrus nutrition. Soil Sci. 55: 87-100.

12. Drake, M., D. H. Sieling, and G. D. Scarseth. 1941. Calcium-boron ratio as an important factor in controlling the boron starvation of plants. Jour. Amer. Soc. Agron. 33: 454-462.

13. Goodall, D. W. 1945. Studies in the diagnosis of mineral deficiency III. The mineral composition of different types of leaves on apple trees in early summer. Jour. Pomol. 21: 103-107.

14. Jones, H. E., and G. D. Scarseth. 1944. The calcium-boron balance in plants as related to boron needs. Soil Sci. 57: 15-24.

15. Marsh, R. P., and J. W. Shive. 1941. Boron as a factor in the calcium metabolism of the corn plant. Soil Sci. 51: 141-151.

16. Naftel, J. A. 1938. The influence of excessive liming on boron deficiency in soils. Soil Sci. 2: 383-384.

17. Overholser, E. L., et al. 1939. Fruit tree response as affected by fertilizer and minor element deficiencies. Wash. State Hort. Soc. Proc. 34: 72-87.

18. Reeve, E., and J. W. Shive. 1944. Potassium-boron and calcium-boron relationships in plant nutrition. Soil Sci. 57: 1-14.

19. Reuther, W., and D. Boynton. 1940. Variations in the potassium content of the foliage from certain New York orchards. Proc. Amer. Soc. Hort. Sci. 37: 32-38.

20. Shear, C. D., H. L. Crane, and A. T. Myers. 1946. Nutrient element balance: A fundamental concept in plant nutrition. Proc. Amer. Soc. Hort. Sci. 47: 239-248.

21. Snedecor, G. W. 1946. Statistical methods. The Iowa State College Press. Ames, Iowa.

22. Wallace, T. 1940. Magnesium deficiency of fruit trees: the comparative base status of the leaves of apple trees and of gooseberry and black currant bushes receiving various manurial treatments under condition of magnesium deficiency. Jour. Pomol. 18: 261-274.

23. White-Stevens, R. H. 1942. Boron deficiency on Long Island. Better Crops with Plant Food, 26: (2). 6.

24. Woodbridge, C. G. 1937. The boron content of apple tissues as related to drought spot and corky core. Sci. Agric. 18: 41-48.

This page intentionally blank.

APPENDIX

Tables I and II

This page intentionally blank.

TABLE I.—The average foliage contents of nitrogen, calcium, magnesium, potassium, and boron of young apple trees grown in sand culture under different levels of supply of calcium, magnesium, potassium and boron

Culture No.	1949					1950				
	Percent of dry weight				PPM	Percent of dry weight				PPM
	N	Ca	Mg	K	B	N	Ca	Mg	K	B
1111	2.72	0.79	0.132	2.06	49.7	2.15	0.32	0.245	0.75	16.9
1112	2.49	0.51	0.092	2.21	68.3	2.25	0.23	0.257	0.95	19.7
1113	2.61	0.50	0.127	1.73	117.1	2.50	0.25	0.283	1.08	32.3
1121	2.53	0.38	0.155	2.34	43.0	2.45	0.32	0.361	1.25	28.5
1122	2.84	0.33	0.111	2.77	64.9	2.79	0.22	0.310	1.62	35.0
1123	2.41	0.30	0.098	2.81	80.6	2.20	0.40	0.420	2.20	45.0
1211	2.61	0.44	0.277	1.75	41.1	2.48	0.16	0.456	0.90	49.2
1212	2.91	0.41	0.225	1.65	44.4	2.32	0.29	0.495	0.86	37.6
1213	2.95	0.32	0.212	1.88	54.3	2.80	0.47	0.539	1.37	78.5
1221	2.85	0.41	0.247	2.11	46.1	2.59	0.19	0.243	1.23	30.9
1222	2.73	0.41	0.264	1.87	59.6	2.32	0.26	0.318	1.15	46.2
1223	2.77	0.37	0.243	2.18	113.6	2.44	0.31	0.275	1.55	47.0
2111	2.89	0.55	0.190	2.37	47.7	2.75	0.45	0.200	0.69	35.5
2112	2.75	0.43	0.159	1.89	70.2	2.49	0.39	0.203	0.55	28.3
2113	3.09	0.45	0.149	2.13	121.2	2.28	0.38	0.176	0.78	22.4
2121	3.03	0.41	0.127	2.61	59.6	2.70	0.38	0.190	1.26	8.2
2122	3.02	0.48	0.160	2.48	61.1	2.41	0.42	0.235	1.45	21.9
2123	2.87	0.39	0.169	2.61	113.3	2.75	0.42	0.215	1.95	28.3
2211	2.79	0.42	0.175	1.50	56.8	2.49	0.35	0.345	0.70	36.3
2212	2.72	0.43	0.197	1.40	50.9	2.77	0.33	0.319	0.79	68.1
2213	2.70	0.27	0.128	1.29	81.7	2.31	0.30	0.247	0.81	131.5
2221	2.88	0.73	0.157	1.94	43.5	2.49	0.41	0.301	1.67	40.1
2222	2.64	0.35	0.113	1.59	50.0	2.29	0.25	0.295	1.52	42.3
2223	2.58	0.31	0.133	1.55	83.1	2.25	0.41	0.289	1.85	49.2
3111	2.55	0.96	0.105	1.55	50.6	2.23	0.50	0.190	0.67	42.9
3112	2.76	1.01	0.105	1.55	60.1	2.37	0.53	0.159	0.91	47.2
3113	2.69	0.93	0.179	1.48	75.1	2.92	0.56	0.150	0.85	75.4
3121	2.53	0.80	0.137	2.15	61.9	2.09	0.37	0.263	1.66	32.5
3122	2.86	1.51	0.099	2.21	53.9	2.02	0.19	0.218	1.35	29.6
3123	2.45	0.73	0.031	2.57	123.0	2.48	0.71	0.295	2.55	66.6
3211	2.58	1.04	0.158	1.52	55.4	2.11	0.51	0.411	0.80	34.5
3212	2.40	0.81	0.112	1.22	57.0	2.02	0.54	0.358	0.70	39.0
3213	2.44	1.07	0.143	1.23	133.2	2.54	0.64	0.337	1.39	49.9
3221	2.49	1.14	0.160	2.19	51.7	2.52	0.94	0.316	1.98	52.5
3222	2.56	0.93	0.225	2.35	54.2	2.11	0.66	0.283	1.78	58.4
3223	2.35	1.19	0.218	2.23	100.6	2.40	0.75	0.265	2.26	105.9

TABLE II.—The average total terminal growth in centimeters made by young apple trees grown in sand culture under different levels of supply of calcium, magnesium, potassium, and boron

Culture No.	Average terminal growth in centimeters	
	1949	1950
1111	136.5	79.6
1112	229.7	80.2
1113	132.8	110.0
1121	219.2	102.0
1122	166.2	99.0
1123	143.0	27.0
1211	217.8	122.0
1212	155.3	66.0
1213	328.2	105.1
1221	269.3	212.5
1222	264.5	310.0
1223	297.7	156.5
2111	74.0	60.0
2112	136.2	85.8
2113	137.5	72.0
2121	146.7	82.0
2122	175.2	171.8
2123	227.0	93.5
2211	236.5	103.6
2212	235.7	120.3
2213	195.0	145.2
2221	156.7	223.8
2222	305.0	253.3
2223	253.3	158.1
3111	96.8	80.0
3112	136.0	120.5
3113	117.5	121.2
3121	251.3	343.2
3122	216.7	222.7
3123	227.7	131.6
3211	231.3	193.5
3212	248.0	194.1
3213	259.7	113.8
3221	264.7	278.5
3222	244.3	180.0
3223	253.5	229.8