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BORON DISTRIBUTION IN SOILS AND RELATED DATA
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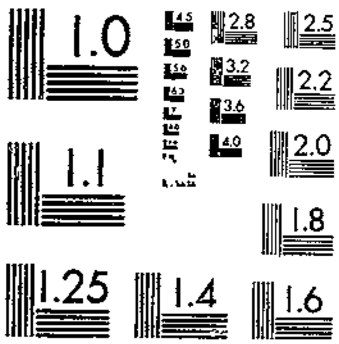

MICROCOPY RESOLUTION TEST CHART
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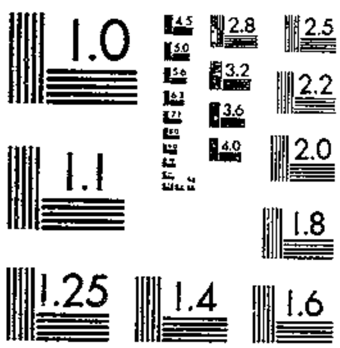

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Boron Distribution in Soils and Related Data [1]

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INTRODUCTION

A great amount of comparatively recent work has established the importance of the dual role of boron as an essential and a toxic element in plant nutrition. Small amounts are necessary in the culture medium for normal growth, a deficiency being marked by well-defined disorders in the plant. Somewhat larger concentrations of boron are injurious, retarding the growth of, or even killing, the plant. Experience has shown that there is a narrow range between the minimum minute quantities that are necessary and the amounts that are toxic. The concentration of boron in soils has therefore become a matter of considerable importance.

Few determinations of boron in soils have been reported. Some of these are old or of questionable accuracy. Available data are largely limited to studies of boron toxicity or deficiency with reference to a very limited number of soils. Boron problems in agriculture have, however, assumed widespread importance. For example, symptoms of boron deficiency are extensive along the Atlantic coast and in the Pacific Northwest.

[1] Submitted for publication May 27, 1941.

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It was the purpose of this investigation to make a systematic survey of the boron status of soils throughout the United States and to attempt to correlate boron content with soil properties and classification. For this purpose a limited number of soil profiles from representative soil series were selected, which may be presumed to present a fair picture of the general situation in the different soil areas. Although no specific study of boron deficiency or toxicity was contemplated, considerable data bearing upon these problems have been accumulated and are included primarily because of their relation to soil character.

HISTORICAL RÉSUMÉ

THE BORON PROBLEM

The first indication of the role of boron in the plant kingdom was the isolation of boric acid from the seeds of an Abyssinian plant, *Maesa picta*, in 1857 by Wittstein and Apoiger (*49*).[2] As early as 1903 Bertrand (*4*) recommended the use of boron in commercial fertilizers as a supplement to nitrogen, phosphorus, and potassium. From the favorable response of plants to the addition of small amounts of boron compounds to the culture medium, Bertrand, 9 years later (*5*), stated that boron in minute quantities is essential to plant growth.

About 1915 Cook and Wilson (*20*) studied the effect of fertilizing with manure treated with borax, or colemanite, to kill fly larvae. In their conclusions they discuss only the toxic effect of boron, although examination of their data reveals an undoubted beneficial effect in one instance on peach trees and a large increase in the yield of potatoes. Further attention was turned to toxic effects of boron during World War I period when substitutes were used in fertilizers for German potash. The potash extracted from western salines contained considerable borax and when applied to crops often caused severe injury (*18*). In the large amount of work reported at that time little reference was made to the beneficial effects of boron on plants (*12*). A little later Kelley and Brown (*31*) reported injury to citrus and walnut trees from excessive concentrations of boron in irrigation water.

In 1921 Brenchley and Warrington (*44*) showed that various legumes could not be grown to maturity without boron. Ten years later Brandenburg (*10*) attributed the heart rot of sugar beets to a boron deficiency. By 1938, 1,800 tons of boric acid were used annually as fertilizer for the sugar beet crop of Europe (*8*). Since the work of Brandenburg, many other boron-deficiency diseases affecting a large variety of crops have been discovered, and now boron is easily the most important of the "minor" elements from the viewpoint of agriculture.

DISTRIBUTION OF BORON

Clarke and Washington (*16*) reported the relative abundance of boron in igneous rocks as 0.001 percent (10 parts per million (p. p. m.)), and Wells (*47*) has estimated 0.01 percent (100 p. p. m.) in the 10-mile crust of the earth. These values are not strictly comparable, but in view of their difference in magnitude it may be of interest to

[2] Italic numbers in parentheses refer to Literature Cited, p. 29.

note that in 118 soil samples in which the authors have determined the total boron content the average is 30 p. p. m. The concentration in sea water is about 4.5 p. p. m. (*37*).

Schaller (*43*) has listed 56 known boron minerals. Natural deposits of borates occur in arid regions and boric acid is present in fumaroles in Tuscany. Tourmaline, a resistant borosilicate containing about 3 percent of boron, is widely distributed in rocks and soils (*41*). Boron is common as an impurity in many minerals and rocks, as Goldschmidt and Peters (*27*) have demonstrated by spectroscopic analyses. They reported from 30 to 300 p. p. m. in shales, iron ores, and corals—all rocks of marine origin. A variety of igneous rocks contained only about 3 p. p. m. The boron content of chalk, limestone, and dolomite was also low. Rader and Hill (*39*), by chemical means, and Young (*51*) and Gaddum and Rogers (*26*) by spectrographic analysis, demonstrated the presence of boron in a variety of natural and artificial fertilizer materials in amounts as high as 0.5 percent.

Although boron is believed to be present in some concentration in all soils, this belief is based less on the few reported determinations than on: (1) The essentiality of boron for plant life; (2) the presence of boron in products of volcanic activity, in plant materials, and in natural waters; and (3) the wide distribution of tourmaline. In 10 topsoils from 7 States, Cook and Wilson (*20*) found from 0.02 to 0.23 p. p. m. of boron. In comparison with other data it is evident that they estimated only a small part of the boron present. Goldschmidt and Peters (*27*) reported 2 to 3 p. p. m. in 7 German soils derived from granite and from 15 to 30 p. p. m. in marsh soils, red soils, and soils formed from shale. Twenty-four soils from Europe and Africa, analyzed by Bertrand and Silberstein (*8*), contained from 7 to 50 p. p. m., 75 percent of them between 10 and 30 p. p. m. The maximum was in a soil from the boraciferous region of Tuscany. High boron content in soils of this area has also been reported by Luchetti (*33*), the amount of boron being inversely proportional to the distance of the sample from a soffione or fumarole. In 10 soil samples Luchetti found water-soluble boron ranged from 2.5 to 16.6 p. p. m.; soluble in 50 percent phosphoric acid between 15 and 61 p. p. m.; and soluble in concentrated sulfuric acid, assumed to be total boron, from 20 to 100 p. p. m. The ratio of water-soluble to total boron was proportional to the calcium carbonate content of the soil.

Rogers and associates (*42*), by spectroscopic analysis, estimated as much as 100 to 500 p.p.m. of boron in certain soils from central Florida. Their average values for 8 soil series, including 132 soils, ranged from 10 to 100 p. p. m.

Aqueous extracts of 5 Russian soils of different great soil groups contained from 0.11 to 0.25 p. p. m. of boron based on the soil (*9*). Askew and associates (*2*, *3*) extracted 0.05 to 0.68 p. p. m. from several New Zealand orchard topsoils with 0.05 N/HCl. Within a profile the amount of soluble boron decreased with depth. The upper 6 inches of a Wakatu soil contained 0.22 p. p. m., whereas the layer from 15 to 30 inches had only 0.03 p. p. m. soluble boron. Several Okanagan (British Columbia) soils yielded from 0.09 to 0.33 p. p. m. boron on extraction with water containing carbon dioxide (*50*). Kelley and Brown (*31*) found as much as 21 p. p. m. soluble boron in California soils toxic to citrus or walnut trees, and as much as 15 p. p. m. has been found in natural waters in that State (*23*).

Boron has invariably been found in plant materials when suitable analytical methods have been employed (*25*). The boron content is not uniform throughout the plant but is usually high in the leaves and flowers (*7*), low in the stems, fruits, and roots (*19*). It is also a function of the maturity of the plant (*48*) and of the available boron in the substrate. As much as 2,200 p. p. m. have been reported (*23*) in fig leaves.

Boron in animal life has received little study. Bertrand and Agulhon (*6*) detected it in small amounts in all of many animal materials examined, and postulated its presence in all animal tissues.

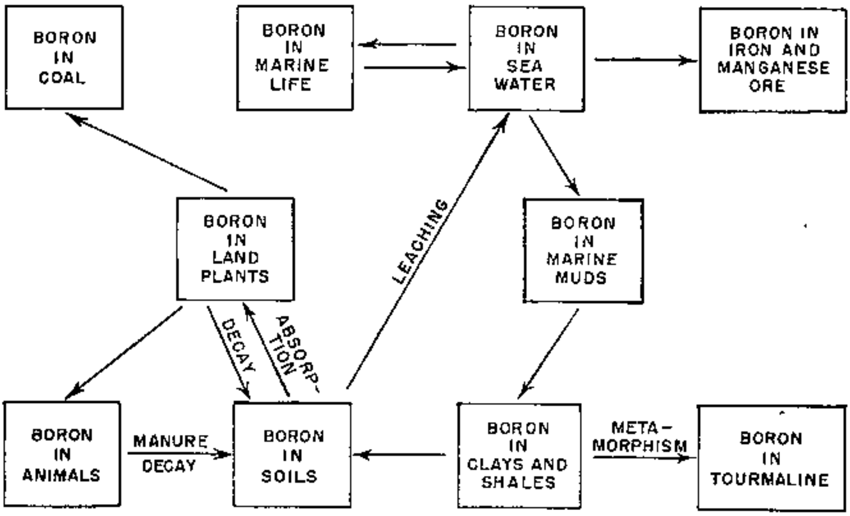

FIGURE 1.—The boron cycle as diagrammed by Dennis (*22*).

The cycle of boron in nature has been diagrammed by Dennis (*22*) as in figure 1. The cycle leaves something to be desired, as it implies the permanent removal of boron into coal formations, iron and manganese ores, and borosilicate minerals. Apparently, however, these materials form an important source for recovery of active boron compounds.

FORMS OF BORON IN THE SOIL

Much of the total boron in soils occurs in particles of resistant rocks and minerals residual from the decomposition of the parent material. Tourmaline is the most common soil mineral of which boron is a characteristic part; in fact, it is the only boron mineral commonly identifiable in soils. It is a complex aluminum borosilicate of iron, magnesium, or other base, and contains about 10 percent of boric oxide (B_2O_3), or 3.1 percent of boron. Most soils contain tourmaline in variable but usually very small amounts. Of 45 American soils examined by Robinson, Steinkoenig, and Fry (*41*), tourmaline was present in 32, but no other boron mineral was identified. Small fragments of tourmaline in soils frequently show bright, clean surfaces, and sometimes the characteristic crystal form (*30*). Such a mineral must be very nearly insoluble and, as pot tests have shown (*23*), its boron is not readily available for plant use. In addition to boron minerals, other relatively insoluble minerals in the soil may contain boron as an important impurity.

Residues of plant and animal materials are a second source of soil boron. The manner of combination of boron in such substances is not definitely known. Since, however, boric acid readily forms stable compounds with mannite, invert sugar, and other polyhydroxy alcohols, it may be associated with sugars and starches in the plant. The organic boron in soils, usually small in amount, should be rather quickly converted by decay into a soluble form available to plants.

The soil boron of greatest agricultural significance is probably that precipitated in the form of inorganic compounds or adsorbed or chemically combined at or near the surface of the soil particles. This store of boron is in quasi equilibrium with the boron in the soil solution, and, though of low solubility, replaces the boron lost from the solution by leaching or absorption by plants. In the laboratory a soil furnishes measurable quantities of boron for 20 or more consecutive leachings (*25*). Cook and Wilson (*20*) and, later, Eaton et al. (*24*) stated that added boron is "fixed" by the soil; that is, rendered comparatively insoluble through reaction between the soluble borates and the components of the soil. By long-continued leaching, however, Eaton et al. were able to recover practically all the added boron. Krügel, Dreyspring, and Lotthammer (*32*) found that 75 percent or more of the boron added as various compounds in fertilizer mixtures could be recovered from the soil by leaching except when the boron was applied as magnesium boracite. In this compound it remained in the soil in an almost unleachable condition.

A single experiment performed in the course of this investigation confirmed the insolubility of magnesium borate. A crystal of boracite ($MgCl_2.6\ MgO.8\ B_2O_3$) weighing 0.1985 gm. was suspended in a liter of distilled water for 6 months with considerable shaking. Although the crystal lost 6.9 mg. in weight, which from the formula should correspond to 1.3 mg. of boron, the solution contained only 0.09 mg. Magnesium chloride was preferentially dissolved, leaving magnesium borate behind almost quantitatively. The boron in such a compound would be very slowly yielded to the soil solution, but in the course of many years it would be rendered completely available.

Liming the soil causes boron to become less available to plants and often induces boron deficiency (*25*, *27*). Whether this is the result of the formation of a relatively insoluble calcium borate, similar to the magnesium compound, or whether it is caused by increased boron fixation by organisms in the soil (*38*) has not been definitely established.

A study of boron in soils involves three quantities: Total boron; soluble boron, or boron in the soil solution; and the reserve or maximum available boron, including both organic boron and that precipitated as inorganic compounds or adsorbed and chemically combined in the soil particles. As most other investigators have been concerned with soluble boron, this report will be devoted chiefly to the other two quantities. From these the store of boron in the relatively insoluble minerals may be calculated.

METHODS OF ANALYSIS

After a survey of methods used for the determination of boron, Scharrer and Gottschalk (*45*) concluded that for the small quantities present in soils and plants either colorimetric or titrimetric methods are suitable. Bertrand and Silberstein (*8*) developed a method based upon the color produced by boric acid with coumarin. Another color method, using quinalizarine, has also been employed (*46*). Although these procedures are very sensitive, a volumetric method seems more satisfactory for the amounts of boron, 0.1 to 2 mg., usually estimated in this work. This method is based upon the formation from boric acid and mannite of a complex acid which is sufficiently ionized to be accurately titrated with a standard base (*25*).

Before the titration can be made the boron must be freed from other elements. The separation of a few parts of boron from a million parts of the complex soil mixture of mineral and organic matter is effected by distillation of boric acid as its methyl ester. After saponification of the ester and removal of the alcohol by distillation, the boric acid may be titrated accurately.

The principal interfering substances in the titration of boric acid are weak acids, quadrivalent germanium, and hexavalent tellurium (*39*). Weak acids hinder accurate determination of the end point, and the two elements form complexes with mannite that titrate as boric acid. Of these, volatile acids and a small part of the germanium may accompany boron in the distillate. Organic and carbonic acids are readily destroyed before the titration. Germanium is rarely, if ever, present in soils in quantities sufficient to interfere with the titration. Weak inorganic acids, such as hydrofluosilicic acid are not produced from soils by the procedures described below in sufficient quantities to cause difficulty, although Rader and Hill (*39*) report possible errors due to this source in the examination of phosphates high in fluorine.

Sulfuric acid, phosphoric acid, and hydrochloric acid with calcium chloride have been used to create the nearly anhydrous acid condition necessary for the distillation of methyl borate. Hydrochloric acid, by reason of its volatility, is obviously unsuited for a method requiring a preliminary, protracted digestion. Either of the two nonvolatile acids could be used as a digestant, but in the distillation with sulfuric acid large quantities of methyl sulfate are produced. Since tests with the two acids on several soils showed the superiority of phosphoric acid in recovery of boron, ease of handling, and decomposition of the soil without caking, 85 percent orthophosphoric acid has been used in the following procedures.

Acid-Soluble Boron

Although tourmaline and other borosilicate minerals likely to be present in the soil are not affected by strong acids, the boron in organic matter, in precipitated borates, or in the soil colloid should be readily liberated as boric acid. Acid digestion of a soil, followed by a methyl alcohol distillation, should therefore furnish a means of separating the maximum available boron. This maximum represents the boron made soluble by reactions short of drastic processes of decomposition and is not to be understood as representing boron immediately available to plants. This latter quantity probably corresponds more nearly to the water-soluble boron. The details of the procedure follow.

Add 75 to 100 ml. of 85-percent phosphoric acid to 50 gm. of air-dry soil, passing a 2-mm. sieve, in a 500-ml. short-neck, round-bottom flask of boron-free glass.[3] The amount of acid used depends upon the composition of the soil; sandy soils require less than soils high in bases or carbonate. Thoroughly mix soil and acid, and heat on a steam bath over night. Disintegrate with a stirring rod any lumps that have formed, cool, add 50 to 100 ml. of anhydrous methyl alcohol, connect the flask in the distillation setup, and shake to mix the added methyl alcohol with the digestion mixture. The anhydrous alcohol in the reservoir should be boiling when the digestion flask is connected to prevent possible stoppage of the inlet tube by the soil mixture. Distill as in steam distillation. Collect about 500 ml. of distillate. During the major portion of the distillation keep the volume of mixture in the digestion flask about constant by regulation of the burners; toward the end the volume may be somewhat decreased.

Make the distillate alkaline to phenolphthalein with an excess of N/5 sodium hydroxide solution, and distill off and recover the methyl alcohol. Transfer the aqueous residue to a platinum dish, evaporate to dryness, and gently ignite to destroy the organic matter. Take up with water and transfer to a 250-ml. beaker or Erlenmeyer flask, rinsing the dish with a few drops of 2 N hydrochloric acid. Dilute to 150 ml., add two to three drops of 1 percent bromthymol blue solution, and acidify with 2 N hydrochloric acid. Boil to expel carbon dioxide, adding more acid if necessary, then cool by immersion in cold water.

Titrate electrometrically. Calomel and glass electrodes were used in this work. Other pairs are equally suitable (*48*). If electrometric equipment is not available, satisfactory results may be obtained by titration, using bromthymol blue as an indicator.

Adjust the solution exactly to a definite pH which is near neutrality with N/2 carbonate-free sodium hydroxide, N/10 hydrochloric acid, and finally with N/50 standard sodium hydroxide. Add 5 gm. of neutral mannite and titrate with the standard N/50 sodium hydroxide to exactly the initial pH. The sodium hydroxide is standardized against known amounts of boric acid in the same manner.

Blank determinations yielded about 0.02 mg. of boron, or 0.4 p. p. m., based on 50 gm. of soil. Small quantities of finely powdered tourmaline added to soils failed to give any measurable increased amount of acid-soluble boron. Agreement in duplicates is usually within 5 to 10 percent, based on the quantities of boron present. Table 1 presents results of duplicate determinations on several soils.

TABLE 1.—*Agreement of duplicate determinations of acid-soluble boron*

Laboratory sample No.	Soil type	Boron (p. p. m.)
10046	Au Train sand	2.4, 2.6.
9478	Nacogdoches fine sandy loam	6.2, 6.2.
C5227	Chester loam	7.0, 6.0,[1] 7.0.[1]
8073	Palouse silt loam	7.4, 6.8.[2]
10084	Carrington loam	13.4, 13.0,[2] 14.0.[2]
C4591	Berks shale loam	18.8, 20.2.
C4028	Huntington silt loam	26.4, 24.4,[2] 24.0,[2] 24.6,[1] 25.6.[1]
C4029	do	27.2, 28.2,[2] 29.2,[2] 29.0,[1] 29.2.[1]
6721	Vernon fine sandy loam	37.0, 39.0.
B17914	Fallon clay	71.2, 74.6.
B17913	do	137, 139.

[1] Determinations by A. E. Yelmgren. [2] Determinations by G. Edgington.

[3] Boron-free glass of the required forms is now obtainable from chemical supply houses.

TOTAL BORON

For complete decomposition of soil, including highly resistant borosilicate minerals, a fusion is necessary. Alkaline fluxes, Na_2CO_3 and K_2CO_3, may be used, but with large quantities of soil these have serious drawbacks. Fusion temperatures are high and difficult to attain. The decomposition of the melt with acid offers difficulties and produces considerable water. The silica is in a soluble form and on addition of acid produces gelatinous silicic acid with probable entrapment of boron.

Sodium acid phosphate, suggested by Jannasch and Noll (*29*), offers several advantages as a fusion agent. The fusion is complete at a relatively low temperature and may therefore be conveniently performed on large samples. The melt is readily removed from the crucible and gives no effervescence or water when decomposed by acid.

An analysis of a black tourmaline from Paris, Maine, gave by acid phosphate fusion 9.75 percent boric oxide (B_2O_3) and by sodium carbonate fusion 9.76 percent and 9.83 percent. In trials with both fluxes on soils, sodium acid phosphate yielded equally high results and was more convenient to use. Samples C1675 and C2106 contained, by carbonate fusion, 37.2 p. p. m. and 28.0 p. p. m. boron, respectively, and by acid phosphate fusion 35.2 and 39.6 p. p. m.

The laboratory procedure is as follows: Mix 10 to 25 gm. of soil ground to pass a 100-mesh sieve with four times its weight of anhydrous sodium dihydrogen phosphate in a 200-ml. iron crucible. Fuse over the combined flames of two or three Meker burners, occasionally rotating the crucible with tongs to insure a complete, uniform fusion. Cool, detach, and pulverize the melt. Dust it into 80 cc. of phosphoric acid in a digestion flask with frequent shaking, and heat on the steam bath over night. Distill and titrate as for acid-soluble boron. Blanks for the reagents have amounted to about 0.09 mg. of boron for 25 gm. of soil. As shown in table 2, duplicate determinations differed by 5 percent or less. From 85 to 100 percent of boron added to the soil in tourmaline was recovered.

TABLE 2.—*Agreement of duplicate determinations of total boron*

Laboratory sample No.	Soil type	Boron (p. p. m.)
C124	Decatur clay loam	17, 18.
C126	do	19, 20.
C291	Ruston fine sandy loam	33, 33, 32,[1] 32,[1]
C2108	Sharkey clay	47, 48.
C4595	Hagerstown stony loam	65, 66.
C132	Maury silt loam	62, 65.[1]

[1] Determinations by O. Edgington.

WATER-SOLUBLE BORON

Many different solutions and methods of extraction have been used for the determination of soluble boron in soils. After testing several of these, Eaton and Wilcox (*25*) favored pressure extraction of the soil in equilibrium with 1.5 times the moisture equivalent percentage of water. Although this procedure gives comparable results for the boron in the soil solution, it is not suitable for a measure of the total water-soluble boron. Krügel, Dreyspring, and Lotthammer (*32*) have shown that a few leachings suffice to remove essentially all the water-soluble boron from soils. As the authors' present purpose is to compare water-soluble boron with other forms, the procedure given below was followed.

Mix 150 ml. of distilled water with 100 gm. of air-dry soil in a 250-cc. boron-free Erlenmeyer flask. Heat the flask in a boiling water bath for 15 minutes, with frequent shaking, then suck the solution from the soil with a Pasteur-Chamberland tube.[4] Repeat, with three 100-ml. portions of water. Make the combined filtrates alkaline with N/2 sodium hydroxide solution, evaporate to dryness in platinum, ignite, and titrate as described. That this procedure removes substantially all water-soluble boron is illustrated by successive extractions of Antioch clay loam. The successive quantities of boron found in the leachates were 8.6, 2.2, 1.6, and 1.1 p. p. m.

Boron in Plant Materials

Consideration of boron in soils, including possible deficiency or toxicity, inevitably involved vegetation growing in the soils. Two methods were used for the determination of boron in plant materials. With the first, a modification of that for acid-soluble boron in soils, 50 to 75 ml. of phosphoric acid was added to 10 to 15 gm. of organic matter and the mixture immediately distilled. The ashing method described by Wilcox (*48*) was used for most of the determinations. It requires less time and makes use of larger samples. Results obtained by the two methods on the same sample showed about the same agreement as duplicate determinations by either method or within 1 to 2 p. p. m. for material containing 50 p. p. m. or less.

ANALYTICAL DATA

Most of the soil samples examined were collected by members of this Division and of the Division of Soil Survey for other studies. They were selected for this investigation as representative of the great soil groups and of the geographical regions of the country. Complete descriptions, as well as physical and chemical data, are available in other publications (*1*, *13*, *14*, *28*, *35*, *36*).[5] Certain data from these sources have been included in table 4. Some samples, including soils of known boron deficiency or toxicity, were collected by the authors or obtained through the help of other persons. Unless otherwise noted, samples are from virgin soils.

Table 3 shows the content of acid-soluble, total, and acid-insoluble boron in a number of soils classified by great groups. Acid-soluble boron is presumably the maximum available boron, whereas acid-insoluble boron, the difference between total and acid-soluble, is a measure of the store of boron in resistant mineral and rock particles. Since the determination of the total involves greater chance for analytical error than does the acid-soluble method, in a few instances the acid-soluble slightly exceeds the total.

All results are expressed in parts per million of the element boron referred to air-dried soil. To convert to boric oxide or borax, multiply by 3.22 or 8.81, respectively.

[4] A piece 3 to 4 inches, cut from the bottom of the tube, suffices.
[5] Also from as yet unpublished material by I. C. Brown and R. S. Holmes.

TABLE 3.—*Boron content of soil profiles in relation to soil groups and parent material*

Laboratory sample No.	Soil type and location	Depth	Acid-soluble boron	Total boron	Acid-insoluble boron	Parent material
	I. PODZOLS					
		Inches	*P. p. m.*	*P. p. m.*	*P. p. m.*	
C1438	Brassua sandy loam, North Groton, N. H.	0- 3	2.0	36	34	Granite.
C1439		3- 4	1.4	21	20	
C1440		4- 9	1.0	10	9	
C1441		9- 19	2.4	16	14	
C1442		19+	1.4	23	22	
	II. GRAY-BROWN PODZOLIC SOILS					
C4591	Berks shale loam (orchard soil), Martinsburg, W. Va.	0- 4	18.8	42	23	Shale.
C4592		4- 12	21.0	49	28	
C4593		12- 20		58		
C4043	Brookston silty clay loam, Fairmont, Ind.	0- 6	28.2	42	14	Calcareous glacial drift.
C4044		6- 20	35.0	42	7	
C4045		20- 34	32.8	41	8	
C4046		34- 74	57.4	60	3	
C4047		74- 85+	61.8	6[illegible]	6	
C1671	Chester loam, Rockville, Md.	2- 10	5.8	30	24	Granite and gneiss.
C1672		10- 34	9.6	26	16	
C1673		34- 60	5.4	35	30	
C4067	Clyde silty clay loam, Winchester, Ind.	0- 8	44.0	46	2	Glacial drift.
C4068		8- 20	43.2	46	3	
C4069		20- 26	41.6	44	2	
C4070		26- 38	35.6	38	2	
C4071		38- 66	64.8	------	------	
C4072		66- 75+	43.8	43.	0	
C4594	Hagerstown stony loam (orchard soil), Charles Town, W. Va.	0- 4	5.8	60	54	Limestone.
C4595		4- 12	6.0	65	59	
C4596		12- 26	12.6	41	28	
C4597		26- 30	11.0	33	22	
C4060	Miami silt loam, Williamsburg, Ind.	0- 2	10.8	32	21	Calcareous glacial drift.
C4061		2- 5	11.6	35	23	
C4062		5- 11	12.8	32	19	
C4063		11- 15	19.2	35	16	
C4064		15- 30	35.4	49	14	
C4065		30- 36	39.4	49	10	
C4066		36+	34.8	41	6	
	III. RED AND YELLOW PODZOLIC SOILS					
3876	Cecil clay loam, Orange County, Va.	0- 6	3.3	10	7	Gneiss and schist.
3877		6- 32	4.7	8	3	
3878			5.4	10	5	
C4881	Cecil clay (cultivated soil), Browns Summit, N. C.	0- 9	4.4	12	8	
C4882		9- 18	6.0	10	4	
C4883		18- 30	5.2	6	1	
C4884		36	3.8	6	2	
4439	Davidson clay loam, Greenville, S. C.	0- 9	2.4	10	8	Basic igneous rock.
4440		9- 35	4.4	6	2	
C123	Decatur clay loam, Russellville, Ala.	0- 2	6.8	32	25	Limestone.
C124		2- 12	6.0	18	12	
C125		12- 40	6.9	------	------	
C126		40- 60	6.6	19	12	
C298	Dunbar fine sandy loam, Graingers, N. C.	0- 5	1.0	27	26	Unconsolidated sediment.
C299		5- 12	.8	31	30	
C300		16- 28	2.4	36	34	
C301		28- 44	3.0	30	27	
C129	Maury silt loam, Ashwood, Tenn.	2- 12	9.8	40	30	Phosphatic limestone.
C130		12- 25	17.8	34	16	
C131		25- 40	32.2	37	5	
C132		40- 60	61.8	62	0	
C133		60- 90	63.0	63	0	
C294	Norfolk fine sandy loam, Bests, N. C.	0- 12	1.6	21	19	Unconsolidated sediment.
C295		12- 34	3.8	20	16	
C296		36- 80	2.6	14	11	
C288	Orangeburg fine sandy loam, Williams, N. C.	0- 6	1.2	24	23	
C289		6- 30	6.0	22	16	
C290		80-100	4.6	14	9	
C291	Ruston fine sandy loam, Fremont, N. C.	0- 10	1.2	33	32	
C292		16- 30	4.4	32	28	
C293		40- 54	6.2	22	16	
146	Tifton fine sandy loam, Worth County, Ga.	0- 14	1.0	9	8	
147		14- 38	1.6	7	5	
148		38- 54	4.0	9	5	
C4912	York silt loam, Bethany, S. C.	0- 2	4.2	26	22	Shale.
C4913		2- 12	4.8	27	22	
C4914		12- 24	6.2	20	23	
C4915		24- 30	5.8	19	13	

TABLE 3.—*Boron content of soil profiles in relation to soil groups and parent material*—Continued

Laboratory sample No.	Soil type and location	Depth	Acid-soluble boron	Total boron	Acid-insoluble boron	Parent material
IV. HALF BOG, GROUND-WATER PODZOL, AND MUCK SOILS						
		Inches	*P. p. m.*	*P. p. m.*	*P. p. m.*	
C305	Bladen loam, Airy Grove School, N. C.	0- 8	1.6	27	25	Unconsolidated sediment.
C306		10- 36	2.8	23	20	
C302	Coxville fine sandy loam, West Crossroads, N. C.	0- 9	2.8	32	29	
C303		26- 34	5.6	25	19	
C313	Pamlico muck, Cove City, N. C.	0- 24	.8	14	13	
C312		40- 60	1.8	17	15	
C308	Portsmouth fine sandy loam, Kinston, N. C.	0- 15	2.4	17	15	
C309		15- 35	2.2	20	18	
C310		50- 60	2.6	19	16	
V. PRAIRIE, CHERNOZEM, AND BROWN SOILS						
C2929	Barnes loam, Labolt, S. Dak.	0- 9	22.4	35	13	Calcareous glacial drift.
C2930		9- 17	21.2	32	11	
C2931		17- 33	32.2	37	5	
C2932		33- 60	27.2	38	11	
10082	Carrington loam, Winthrop, Iowa	0- 3	12.0	25	13	
10083		3- 13	12.6	25	12	
10084		13- 22	13.4	25	12	
10085		22- 43	14.8	28	13	
10086		43- 70	19.6	29	9	
10087		70- 84	19.4	29	10	
8736	Marshall silt loam, Clarinda, Iowa	0- 13	23.8	41	17	Loess.
8737		13- 24	22.2	34	12	
8738		24- 45	20.4	25	5	
8739		45- 71	12.8	28	15	
B19616	Light grayish-brown silt loam, Pueblo, Colo.	0- 6	19.2	22	3	Calcareous shale.
B19617		6- 12	20.8	27	6	
B19618		12- 24	33.8	38	4	
B19619		24- 36	27.8	43	15	
B19620		36- 48	39.4	40	1	
B19621		48- 58	34.4	35	1	
B19622		58- 62	27.8	27	------	
VI. RED DESERT SOILS						
C3419	Muroc sandy loam, Kern Co., Calif.	0- 2	8.8	11	2	Granite.
C3420		2- 5	10.0	11	1	
C3421		5- 11	13.6	15	1	
C3422		11- 14	13.8	14	0	
C3424		44- 50	5.4	6	1	
VII. NONCALCIC BROWN (SHANTUNG BROWN) SOILS						
C5091	Fallbrook fine sandy loam (orchard soil), Escondido, Calif.	0- 6	3.7	8	4	Granite.
C5092		6- 20	4.0	8	4	
C5764	Rincon loam, Hollister, Calif.	0- 6	12.4	19	7	Unconsolidated river sediment.
C5765		6- 36	14.0	15	1	
C5766		36- 72	14.4	15	1	
C5774	Sierra sandy loam, Riverside, Calif.	0- 6	4.0	7	3	Igneous rock.
C5775		6- 36	3.0	10	10	
C5085	Soil at Himalaya tourmaline mine, Mesa Grande, Calif.	0- 2	4.0	98	93	Pegmatite.
C5086		2- 10	5.3	66	61	
C5087		10- 16	5.5	62	56	
C5088		16-120	2.8	15	12	
C5089		at 18	2.3	4	2	
VIII. ALLUVIAL SOILS						
C4734	Chehalis silty clay loam, Chitwood, Oreg.	0- 8	9.0	16	7	Unconsolidated river wash.
C4735		8- 18	6.8	13	6	
C4736		18- 36	10.0	16	6	
C4928	Huntington silt loam, Elliston, Va. (cultivated soil)	0- 8	25.4	83	57	Unconsolidated alluvium from limestone areas.
C4929		8- 24	27.2	88	61	
C4930		at 30	28.0	69	40	
C2106	Sharkey clay, Terrebonne Parish, La.	0- 6	37.6	40	3	Mississippi River wash.
C2107		10- 24	45.5	59	13	
C2108		48- 80	41.4	48	7	

In order to extend this survey to as many soils as possible within a limited time, only one form of boron was determined in an additional number of soils. The acid-soluble method was used, since it is much more rapid, and the results probably have more agricultural significance. These supplementary data are listed in table 4. Tabulated with it are the pH and colloid content of the soil and molecular ratios of the soil colloid, to show the relationship between the physical and chemical properties of a soil and its acid-soluble boron content. Parent material is given in parentheses under description of the sample. For completeness, soils from table 3 have been included when the additional data were available, and to distinguish them they have been listed by only the soil series name.

TABLE 4.—*Acid-soluble boron content of soils in relation to pH, colloid content, silica-sesquioxide ratio, and silica-base ratio*

I. PODZOLS

Laboratory sample No.	Description of samples	Depth	Acid-soluble boron	Soil pH	Colloid	In colloid: $\frac{SiO_2}{R_2O_3}$	In colloid: $\frac{SiO_2}{\text{Total bases}}$
		Inches	*P.p.m.*		*Percent*		
10644	Au Train sand (glacial drift), Luce County, Mich.	0- 2	14.0	5.8	4.6	4.72	3.7
10645		2- 10	1.6	4.3	.7	4.88	20.0
10646		10- 12	2.6	4.6	.8	.95	6.8
10647		12- 40	2.8	5.2	1.3	.78	8.0
10648		40- 60	2.6	5.9	.4		
C1438	Brassua sandy loam	0- 3	2.0	3.0	1.3	2.99	14.3
C1439		3- 4	1.4	3.7	5.1	1.05	14.6
C1440		4- 9	1.0	4.5	1.8	.68	19.9
C1441		9- 19	2.4	4.6	.5	.83	9.8
C1442		19+	1.4	5.4	.5	1.53	5.2

II. GRAY-BROWN PODZOLIC SOILS

Laboratory sample No.	Description of samples	Depth	Acid-soluble boron	Soil pH	Colloid	In colloid: $\frac{SiO_2}{R_2O_3}$	In colloid: $\frac{SiO_2}{\text{Total bases}}$
C4043	Brookston silty clay loam	0- 6	28.2	6.6	24.3	2.68	5.9
C4044		6- 20	35.0	6.4	29.2	2.73	6.4
C4045		20- 34	32.8	6.8	36.5	2.80	6.9
C4046		34- 74	57.4	7.2	35.9	2.50	5.8
C4047		74- 85+	61.8	7.8	28.6	2.48	5.1
C1671	Chester loam	2- 10	5.8	4.8	19.7	1.72	13.0
C1672		10- 34	9.6	4.8	24.5	1.74	13.6
C1673		34- 60	6.4	4.9	17.1	1.53	13.9
10362	Clinton silt loam (loess), La Crosse, Wis.	0- 8	10.2	5.9	11.2	2.69	8.1
10364		20- 32	19.2	5.2	21.8	2.62	8.0
10365		32- 44	17.6	5.4	16.2	2.55	9.1
10366		44- 66	17.6	5.6	21.4	2.44	13.3
C4067	Clyde silty clay loam	0- 8	44.0	6.4	41.2	2.80	6.6
C4068		8- 20	43.2	6.9	46.2	2.82	6.8
C4069		20- 26	41.6	7.2	46.1	2.72	7.0
C4070		26- 38	35.6	7.2	41.9	2.55	6.9
C4071		38- 66	64.8	7.1	36.9	2.31	5.7
C4072		66- 75+	43.8	8.0	23.0	2.45	5.7
C4060	Miami silt loam	0- 2	10.8	6.3	15.9	2.57	6.7
C4061		2- 5	11.6	5.9	15.5	2.52	7.2
C4062		5- 11	12.8	5.5	16.4	2.43	7.2
C4063		11- 15	19.2	5.5	22.7	2.37	7.3
C4064		15- 30	35.4	5.2	36.9	2.40	7.0
C4065		30- 36	39.4	6.4	37.4	2.37	6.5
C4066		36+	34.8	7.6	21.3	2.42	6.2
B407	Muskingum silt loam (shale), Zanesville, Ohio	0- 7	16.0	4.7	19.9	2.26	7.8
B408		8- 13	28.4	4.8	27.3	2.06	7.6
B409		14- 24	29.2	4.8	25.3	1.07	8.3
B410		25- 46	20.0	4.8	20.3	2.12	9.1
B411		47- 72	30.4	6.4	19.0	2.20	7.6
6719	Vernon fine sandy loam (shale), Guthrie, Okla.	3- 10	10.0	7.0	9.0	2.44	7.4
6720		10- 27	23.8	6.4	23.8	2.34	7.5
6721		27- 68	30.0	6.7	27.4	2.35	6.7

TABLE 4.—*Acid-soluble boron content of soils in relation to pH, colloid content, silica-sesquioxide ratio, and silica-base ratio*—Continued

Laboratory sample No.	Description of samples	Depth	Acid-soluble boron	Soil pH	Colloid	In colloid: $\frac{SiO_2}{R_2O_3}$	In colloid: $\frac{SiO_2}{\text{Total bases}}$
	III. RED AND YELLOW PODZOLIC SOILS						
		Inches	*P.p.m.*		*Percent*		
C6331	Arredondo fine sand (unconsolidated sediment), Alachua Co., Fla.	0- 36	0.4	6.5	-----	-----	-----
4439	Davidson clay loam	0- 9	2.4	6.4	23.8	-----	-----
4440		9- 35	4.4	5.2	60.4	1.80	-----
C123	Decatur clay loam	0- 2	6.8	5.9	24.6	1.71	12.9
C124		2- 12	6.0	5.7	28.4	1.71	14.1
C125		12- 40	6.9	5.0	48.0	1.63	15.6
C126		40- 60	6.6	4.9	59.8	1.55	20.4
C298	Dunbar fine sandy loam	0- 5	1.0	4.9	4.7	2.35	35.6
C299		5- 12	.8	4.5	7.5	1.97	35.0
C300		16- 28	2.4	4.4	16.0	1.96	39.1
C301		28- 44	3.0	4.4	23.0	1.81	36.6
6678	Kirvin fine sandy loam (sedimentary clay), Tyler, Tex.	0- 12	2.6	6.2	5.6	2.02	17.5
6679		12- 24	13.2	4.5	59.4	1.74	17.7
6680		24- 51	12.0	4.2	50.0	1.89	18.6
6681		51- 63	7.2	3.9	32.3	2.03	20.3
6682		63- 75	3.0	4.0	7.3	1.80	24.0
C129	Maury silt loam	2- 12	9.3	5.7	19.9	2.04	9.1
C130		12- 25	17.8	5.6	29.9	1.80	6.2
C131		25- 40	32.2	5.2	40.9	1.66	2.8
C132		40- 60	61.8	4.9	45.5	2.24	4.7
C133		60- 90	63.0	5.7	41.5	2.70	4.6
9475	Nacogdoches fine sandy loam (limestone), Tyler, Tex.	0- 8	4.0	5.3	16.1	1.07	12.9
9476		8- 18	7.4	4.4	47.1	1.21	27.8
9478		40- 66	6.2	5.0	31.7	1.53	29.4
C294	Norfolk fine sandy loam	0- 12	1.6	5.1	4.9	1.57	21.4
C295		12- 34	3.8	4.6	23.5	1.51	19.7
C296		36- 80	2.6	4.6	30.1	1.57	29.6
C288	Orangeburg fine sandy loam	0- 6	1.2	5.1	3.0	1.21	15.3
C289		6- 30	6.0	4.8	46.5	1.19	21.9
C290		80-100	4.6	4.6	27.7	1.77	35.7
C291	Ruston fine sandy loam	0- 10	1.2	6.0	6.7	1.54	11.9
C292		16- 30	4.4	5.0	28.3	1.39	18.1
C293		40- 54	6.2	4.8	29.6	1.61	25.0
	IV. GROUND-WATER PODZOL, HALF BOG, AND MUCK SOILS						
C305	Bladen loam	0- 8	1.6	4.4	11.4	2.33	34.1
C306		10- 38	2.8	4.3	23.9	2.11	58.8
C302	Coxville fine sandy loam	0- 9	2.8	4.3	13.5	2.19	27.0
C303		26- 34	5.6	4.4	31.6	1.95	20.9
C311	Pamlico muck	0- 36	1.0	3.8	3.1	2.28	30.0
C312		40- 60	1.6	4.3	14.8	2.20	28.0
C313		0- 24	.8	3.8	5.4	2.09	27.3
C308	Portsmouth fine sandy loam	0- 15	2.4	4.1	3.0	2.41	37.0
C309		15- 35	2.2	4.3	11.1	2.19	62.0
C310		50- 60	2.6	4.4	11.9	2.30	40.6
	V. PRAIRIE, CHESTNUT, CHERNOZEM, AND BROWN SOILS						
C2929	Barnes loam	0- 9	22.4	6.9	28.7	3.05	7.0
C2930		9- 17	21.2	7.1	25.3	3.00	7.1
C2931		17- 33	32.2	8.1	35.6	3.25	7.1
C2932		33- 60	27.2	8.2	31.5	3.36	7.3
10082	Carrington loam	0- 3	12.0	5.5	21.2	2.33	8.5
10083		3- 13	12.0	5.2	22.5	2.39	8.7
10084		13- 22	13.4	4.9	24.5	2.38	9.0
10085		22- 43	14.8	5.1	26.2	2.30	9.3
10086		43- 70	19.6	6.4	23.8	2.32	8.7
10087		70- 84	19.4	8.1	11.0	2.36	8.0
6843	Colby silty clay loam, Hays, Kans. (loess).	10- 20	16.4	8.4	32.4	3.41	6.0
6844		20- 33	17.4	8.5	30.3	3.47	5.7
6846		47- 60	12.2	8.5	00.0	3.57	5.8
6847		60- 72	19.0	8.5	26.8	3.56	6.2
8736	Marshall silt loam	0- 13	23.6	5.5	32.4	2.91	7.6
8737		13- 24	22.2	5.6	34.6	2.88	7.7
8738		24- 45	20.4	5.6	28.2	2.91	8.2
8739		45- 71	12.5	5.7	20.3	2.83	8.7

TABLE 4.—*Acid-soluble boron content of soils in relation to pH, colloid content, silica-sesquioxide ratio, and silica-base ratio*—Continued

V. PRAIRIE, CHESTNUT, CHERNOZEM, AND BROWN SOILS—Continued

Laboratory sample No.	Description of samples	Depth	Acid-soluble boron	Soil pH	Colloid	In colloid: $\frac{SiO_2}{R_2O_3}$	In colloid: $\frac{SiO_2}{\text{Total bases}}$
		Inches	*P.p.m.*		*Percent*		
8069	Palouse silt loam (loess), Pullman, Wash.	0- 20	8.8	6.7	24.0	2.48	6.6
8070		20- 33	8.8	6.9	33.8	2.45	7.1
8071		33- 62	7.6	7.0	32.0	2.45	7.2
8072		62- 75	7.4	7.1	26.6	2.67	7.4
8073		75- 84	7.4	7.3	25.9	2.61	7.0
B23267	Scobey silt loam (glacial drift), Teton Co., Mont.	0- 5	38.8	---	---	---	---
B23268		5- 14	33.8	---	---	---	---
B23269		14- 36	26.6	---	---	---	---
B23270		36- 44	17.8	---	---	---	---
B23271		44- 54	31.2	---	---	---	---
6797	Shelby silt loam (glacial drift), Bethany, Mo.	0- 7	11.4	5.4	24.3	2.65	8.8
6798		8- 12	15.6	5.6	48.7	2.62	9.1
6799		12- 20	16.4	7.0	45.4	2.60	8.7
6800		20- 24	15.4	8.2	37.3	2.60	7.8
6801		24- 48	19.8	8.6	29.7	2.71	7.3
6802		48- 60	20.2	8.6	31.0	2.67	7.4
6802B		60- 84	23.6	8.7	36.0	2.91	7.6
VI. RED DESERT SOILS							
C3419	Muroc sandy loam	0- 2	8.8	7.4	9.0	2.46	6.0
C3420		2- 5	10.0	7.4	35.9	2.52	6.9
C3421		5- 11	13.6	7.6	34.5	2.61	6.9
C3422		11- 14	13.8	8.4	29.5	2.86	6.6
VII. RENDZINA SOILS							
6096	Houston clay (limestone), Temple, Tex.	0- 3	16.4	6.1	44.9	3.26	5.5
6097		14- 20	12.2	8.1	46.6	3.24	4.6
6098		36- 50	11.2	8.2	44.1	3.25	5.4
VIII. ALLUVIAL SOILS							
C3282	Bibb silty clay loam, Bastrop, La.	0- 8	10.6	4.3	19.8	2.74	10.7
C3283		8- 20	13.0	4.3	19.9	2.64	8.1
C3284		20- 30	18.0	4.6	31.9	2.74	8.7
C3002	Havre silt loam, Fort Peck, Mont. (Missouri River)	0- 12	41.8	8.1	35.1	3.42	6.8
C3003		12- 20	46.8	8.1	54.4	3.33	6.6
C3004		20- 32	41.0	8.4	31.2	3.31	6.8
C3005		52- 82	45.8	8.1	59.5	3.33	7.6
C3006		82-100	33.2	8.8	19.2	3.23	7.2
C2999	Havre clay, Nashua, Mont. (Milk River)	0- 8	45.2	7.7	47.6	3.42	6.9
C3000		15- 25	48.2	8.4	30.7	3.50	7.2
C3001		40- 46	61.0	8.4	48.7	3.44	7.3
C1908	Huntington silt loam, Columbia, Tenn. (Duck River)	0- 10	14.4	5.7	24.3	2.28	6.4
C1909		12- 28	13.8	6.1	33.9	2.42	6.5
C1910		38- 60	16.6	5.4	34.7	2.37	7.1
C1911	Huntington very fine sandy loam, Grainger Co., Tenn. (Clinch River)	0- 14	35.4	7.5	15.6	2.19	6.5
C1912		14- 34	34.2	7.8	17.0	2.13	6.4
C1913		34- 62	38.2	7.6	14.6	2.26	6.4
C2106	Sharkey clay, Terrebonne Parish, La.	0- 6	37.0	5.9	73.8	3.17	9.1
C2107		6- 24	45.5	7.1	81.0	3.11	9.0
C2108		43- 80	41.4	7.1	81.5	3.46	8.0
C3264	Sharkey clay, Forrest City, Ark.	0- 8	27.8	5.9	56.5	3.06	8.3
C3205		8- 20	27.2	5.0	58.7	3.10	8.5
C3266		20- 44	30.0	4.8	69.3	3.12	8.1
C2072	Wabash silt loam, New Albin, Iowa	0- 10	20.2	6.4	30.7	2.69	7.1
C2973		10- 25	10.4	6.9	32.8	3.12	7.6
C2974		28- 42	10.4	7.9	14.4	3.22	5.9
C2975		44- 62	20.4	7.5	32.0	3.13	6.0
C2976		68- 79	12.0	7.7	17.4	3.13	6.2
C2977		80- 94	15.0	7.8	21.5	3.33	6.0
C1922	Yazoo very fine silt loam, Vacherie, La.	0- 6	11.8	5.9	13.0	3.16	7.4
C1923		10- 24	23.6	7.1	28.3	3.01	7.8
C1924		48- 80	20.2	6.8	29.2	3.07	8.1

The data in table 4 are summarized in table 5. Averages have been given to show the change in boron content with change in colloid content and certain chemical properties of the soils.

Table 5.—*Variations of acid-soluble boron with pH, colloid content, silica-sesquioxide ratio, and silica-total base ratio*

Variations with pH			Variations with colloid content			Variations with silica-sesquioxide ratio			Variations with silica—total base ratio		
pH	Samples	Average acid-soluble boron	Colloid content	Samples	Average acid-soluble boron	$\frac{SiO_2}{Fe_2O_3+Al_2O_3}$	Samples	Average acid-soluble boron	$\frac{SiO_2}{\text{Total bases}}$	Samples	Average acid-soluble boron
	No.	*P.p.m.*	*Pct.*	*No.*	*P.p.m.*		*No.*	*P.p.m.*		*No.*	*P.p.m.*
4.6	24	4.26	10	22	3.01	1.5	10	3.32	20+	25	3.35
4.6–5.5	42	13.57	10–20	27	13.56	1.5–2.0	26	7.63	10–20	19	6.08
5.0–6.5	30	18.81	20–30	45	17.87	2.0–2.5	45	19.40	8–10	28	19.80
6.6–7.5	26	26.28	30–40	31	23.52	2.5–3.0	36	21.65	6.5–8	51	25.07
7.6+	32	28.01	40+	29	29.32	3.0+	35	26.49	6.5	28	27.65
	154	18.29		154	18.29		152	18.49		151	18.59

Table 6 is a summary of the results in tables 3 and 4. Averages have been calculated for acid-soluble, total, and acid-insoluble boron by great soil groups and by types of soil parent material. Omitted from the average is the abnormal soil from Mesa Grande, Calif. (C5085–5089), derived from a pegmatite vein rich in tourmaline.

Table 6.—*Mean boron content of soils with reference to soil groups and soil parent material*

Soil groups and parent material	Acid-soluble boron		Total boron		Acid-insoluble boron	
	Samples	Average	Samples	Average	Samples	Average
Group:	*Number*	*P. p. m.*	*Number*	*P. p. m.*	*Number*	*P. p. m.*
Half Bog, Ground-Water Podzol, and muck	10	2.36	9	21.6	9	18.9
Podzol	12	3.26	5	21.2	5	19.8
Noncalcic Brown	7	7.93	7	11.7	7	3.9
Red and Yellow Podzolic	47	7.94	37	22.6	37	14.2
Red Desert	5	10.32	5	11.4	5	1.0
Rendzina	3	13.27				
Gray-Brown Podzolic	33	22.59	22	43.9	21	20.5
Prairie, Chestnut, Chernozem, and Brown	48	23.45	27	35.3	27	7.6
Alluvial	38	27.00	9	48.0	9	22.2
Total	203	17.14	121	30.0	120	13.9
Parent material:						
Sandstone	2	3.70				
Unconsolidated sediment	33	4.23	28	20.8	28	17.3
Igneous rock	26	5.19	26	14.1	26	8.9
Loess	17	14.02	4	32.0	4	12.2
Limestone	19	15.95	12	42.0	12	21.9
Shale	14	19.04	7	35.7	6	21.8
Glacial drift	52	25.85	35	38.6	35	8.6
Alluvium	38	27.00	9	48.0	9	22.2
Total	201	17.14	121	30.0	120	13.9

DISCUSSION OF DATA

Relation of Boron Content to Soil Parent Material and Great Soil Groups

This survey confirms the belief, expressed earlier, that boron is universally present in soils. Approximately 200 soil samples, representing various great soil groups, geographical regions, and types of parent material, have been examined. In all, boron was readily detected. Concentrations of total boron range from 4 to 98 p. p. m., with an average of 30. Acid-insoluble boron, or that present in resistant mineral and rock particles, accounts for an average of 14 p. p. m., or about 45 percent of the total. About 17 p. p. m. is in an acid-soluble form and presumably represents the maximum available for plant growth.

The amount of boron present in a soil is dependent on two factors—the boron content of the parent material and the intensity and efficiency of weathering during and subsequent to rock decomposition and soil formation. Weathering may either concentrate or dissipate boron, depending on the form in which it occurs. Tourmaline and other resistant borosilicate minerals are little affected by climatic agencies and, therefore, tend to be concentrated as the more soluble components are removed. Assuming that all acid-soluble boron is present as tourmaline, the average of 14 p. p. m. represents an average soil content of about 400 p. p. m., or 0.04 percent of that mineral. The Hagerstown and Huntington samples, with 60 p. p. m. acid-insoluble boron, by this reasoning contain about 1,800 p. p. m., or nearly 0.2 percent tourmaline. As the Hagerstown is residual from limestone, resistant minerals in the parent rock would be greatly concentrated during soil formation. In the Huntington, an alluvial soil, heavy particles of tourmaline may have been concentrated by stream action.

Boron in decomposable minerals in the parent material is partially lost through weathering, and the remainder is present in the soil in acid-soluble condition. The concentration of this boron may either increase or decrease, depending on the relative rate of removal of boron with respect to the other components. The accumulation of soluble borates in the ocean and in desert regions, and the ready leachability of most borates added to the soil, suggest that, in general, boron is more rapidly carried away than most other elements.

As shown in table 6, the boron content of soils in general reflects the boron content of the parent material. In accordance with the results of Goldschmidt and Peters (*27*), soils formed from igneous rocks are low in boron and those from shales high. Limestone soils, through intensive concentration in their formation, are high, despite low boron content of the rock. In these three groups, in contrast with the general average, acid-insoluble boron is higher than acid-soluble, indicating a relatively large amount of tourmaline. The total boron content of soils formed from unconsolidated sediment is nearly as high as the average, but it is practically all acid-insoluble. A maximum of not to exceed 4 p. p. m. is available to plants. Many of these are Atlantic Coastal Plain soils of the Norfolk and related series formed from almost identical parent material. Inspection of the data for the individual soils (table 3) reveals their great similarity in boron content. In the deposition of the sandy sediments, considerable boron was included in resistant minerals, little in clays and easily decomposed rock particles.

Soils formed from glacial drift, loess, and alluvium are high in boron, most of it acid-soluble. These three parent materials include rock or soil of any and all kinds. Loess and alluvium are largely composed of very fine particles that may be expected to be high in acid-soluble and low in insoluble boron. Heavy particles of tourmaline, may, however, be concentrated sporadically with alluvium as in the Huntington.

Generalizations on the relation of the parent material to the boron content of the soil are complicated and obscured by the very sporadic distribution of tourmaline and by effects of weathering. Samples from a tourmaline-rich pegmatite vein at Mesa Grande, Calif. (table 3), exemplify the uneven occurrence of the boron mineral. Samples C5085 to C5088, apparently formed directly from the vein, are very high in total boron except at the lowest depth. The very low acid-soluble boron content is indicative of the low rate of solution of boron in tourmaline. Sample C5089 was collected about a hundred yards uphill from the other samples where a cut exposed this clay immediately over the pegmatite vein. This sample is very low in boron.

The average boron content of the great soil groups affords evidence on the effects of weathering. Very low in acid-soluble boron are the thoroughly leached Podzols. The removal of most of the clays concentrated resistant minerals in the A horizon. Consequently, total boron is highest in that horizon and lowest in the B zone of accumulation. Likewise low in soluble and high in insoluble boron are the Half Bog, Ground-Water Podzol, and muck soils, which are formed under a high water table with removal of soluble constituents. Of particular interest is the very low acid-soluble boron content of the highly organic mucks, showing the rapidity and completeness with which organic boron is rendered soluble. This group of soils, however, is derived from coastal plains unconsolidated sediment and owes its low boron content partly to the parent material.

The rather intensive leaching which formed the Red and Yellow Podzolic soils likewise left them fairly low in soluble boron. Some from this group are from unconsolidated sediment, but since the others (Cecil, Davidson, York, etc.) are also low, parent material is probably not the determining factor. The acid-soluble boron is about average and tends to be higher in the more thoroughly weathered topsoil. The Maury, residual from phosphatic limestone, is strikingly different. Its high acid-soluble boron content of the lower horizons is associated with a high concentration of calcium phosphate and possibly is due to parent material.

The Gray-Brown Podzolic soils are less leached and contain much more boron. Both soluble and total boron generally increase with depth. The eastern members resemble the Podzols and Red and Yellow Podzolic soils in that most of the boron is acid-insoluble. The others have about the same total, but the major part of it is acid-soluble. This group combines high boron parent material (shale, calcareous glacial drift, and limestone) with moderate leaching, to give a very high average boron content. The variation in boron content with drainage is illustrated by the profiles of Miami silt loam (C4060–4066), Brookston silty clay loam (C4043–4047), and the Clyde silty clay loam (C4067–4072). These soils are developed on the same parent material and are similar in character except as influenced by drainage. In the topsoils, the Miami silt loam, the best drained of the three, contains about one-third as much acid-soluble boron as the Brookston silty clay loam and one-fourth as much as the Clyde silty clay loam, the poorest drained. The water-soluble boron of these soils (see table 8) also differs markedly. This is particularly interesting because Cook (*21*) recently reported boron deficiency in Michigan, as evidenced by heart rot of sugar beets, more frequent in Miami soils as compared with Brookston soils of similar texture.

The soils of the Prairie, Chernozem, Chestnut, and Brown groups are formed under less rainfall than the Gray-Brown Podzolic soils, and contain a little more acid-soluble boron and somewhat less acid-insoluble and total. Seventy-five percent of the total is acid-soluble, the highest for any group except the desert soils. While soluble boron increases with depth in one or two soils, in general the boron content of a profile is fairly uniform. The high boron parent materials, loess and glacial drift, combined with limited rainfall, produce a very high acid-soluble boron average.

The low boron content of the Red Desert and Noncalcic Brown soils, all from California, is clearly the result of parent materials, as these soils have been little leached. They have been formed from igneous rocks and unconsolidated sediments. Most of the boron is acid-soluble and varies little in the profile.

Relation of Acid-Soluble Boron to Soil Properties

The amount of acid-soluble boron retained by a soil despite weathering would seem to be dependent on the soil characteristics. Of the four physical and chemical properties tabulated with boron content in tables 4 and 5, two—the pH and colloid content—seem to be determinative factors. The two molecular ratios are apparently related to boron content, because all three are largely expressions of climatic influence.

Very acid soils are very low in soluble boron. The efficient removal of boron from the Podzols, Half Bog, and muck soils has probably been enhanced by their low pH. Since boric acid is a very weak acid, a tenth-molar solution having a pH of 6.6, in an acid soil like the Brassua, with a pH of 4, insoluble borates should be converted into readily soluble boric acid. With decreasing soil acidity the average boron content increases. This increase is more rapid with the very acid soils and less rapid as neutrality is approached.

The average acid-soluble boron content increases regularly with increasing colloid content from 3.0 p. p. m. in soils with less than 10 percent colloid to 29.3 p. p. m. in those with over 40 percent (see table 5). The Podzols, very low in soluble boron, are poorest in colloid, whereas the alluvial soils almost certainly owe their high boron status to the concentration of fine particles in their formation. The relationship is perhaps better shown by the change in boron content within a profile, since these variations in parent material and weathering are largely eliminated. In the Red and Yellow Podzolic soils there is almost invariably an increase in acid-soluble boron in the B horizon coincident with a decided increase in colloid content.

The Kirvin fine sandy loam contains in the topsoil 2.6 p. p. m. boron and 5.6 percent colloid; with increasing depth, these change to 13.2 p. p. m. and 59.4 percent, then to 12.0 p. p. m. and 50.0 percent, 7.2 p. p. m. and 32.3 percent, and, finally, 3.0 p. p. m. boron and 7.3 percent colloid. Also, in the Wabash silt loam and Yazoo very fine silt loam, two alluvial soils, when there is an appreciable change in colloid content there is a corresponding variation in the amount of acid-soluble boron. The Prairie, Chestnut, Chernozem, and Brown soils are fairly consistently high in both boron and colloid in the profile.

The dependence of the acid-soluble boron on colloid content indicates that much of that form of boron in the soil is held in the colloid. To throw light on this point boron was determined in several colloids. During the extraction of the colloid from the soil, large quantities of water are used and some soluble boron is removed from the colloid. The quantity removed, however, is only about 1 p. p. m. For example, the residue from evaporation of the water used in extraction of 3,400 gm. of the Sharkey soil weighed 2.15 gm. and contained 1,160 p. p. m. boron, or 0.74 p. p. m. boron, based on the weight of the soil sample.

The boron content of a number of colloids together with other pertinent soil data are given in table 7. The number and distribution of these colloids are necessarily limited to those separated in studies of other problems which were available in sufficient quantities for accurate boron determinations.

TABLE 7.—*Boron content of certain soil colloids in relation to lime and magnesia content and pH of the soils*

Laboratory sample No.	Soil series	Depth	Acid-soluble boron		Colloid in soil	CaO in colloid	MgO in colloid	pH of soil
			In colloid	In soil				
		Inches	*P. p. m.*	*P. p. m.*	*Percent*	*Percent*	*Percent*	
C305	Bladen loam	0- 8	11	1.6	11.4	0.57	0.30	4.4
C294	Norfolk fine sandy loam	0- 12	12	1.6	4.9	.35	.58	5.1
C290	Orangeburg fine sandy loam	80-100	16	4.6	27.7	.43	.25	4.0
C292	Ruston fine sandy loam	16- 30	16	4.4	28.3	.30	.50	5.0
C1671	Chester loam	2- 10	20	5.8	10.7	.11	1.08	4.8
C129	Maury silt loam	2- 12	33	9.8	10.9	1.14	1.25	5.7
6798	Shelby silt loam	8- 12	36	15.6	48.7	1.28	1.98	5.6
6801	do	24- 48	44	19.8	29.7	2.16	2.06	8.6
C2918	Carrington loam	13- 22	49	13.4	24.5	.94	1.71	4.9
C2106	Sharkey clay	0- 6	69	37.0	73.8	1.27	1.99	5.0
C2107	do	10- 24	73	45.5	81.0	1.08	2.32	7.1
C2108	do	48- 80	72	41.4	81.0	1.20	2.48	7.1
C2921	Carrington loam	70- 84	58	19.4	11.0	1.48	.79	8.1
C4044	Brookston silty clay loam	0- 20	99	35.0	29.2	1.50	2.65	6.4
C4058	Clyde silty clay loam	8- 20	102	43.2	40.2	1.55	2.51	6.9
C3002	Havre clay	0- 12	105	41.8	31.2	1.64	2.96	8.1
C3003	do	12- 20	104	46.8	54.4	1.74	2.91	8.1
C3004	do	20- 52	105	41.0	31.2	1.69	2.88	8.4
C4000	Miami silt loam	15- 30	108	35.4	30.9	1.04	2.30	6.2
C2931	Barnes loam	17- 33	110	32.2	35.6	5.03	2.68	8.1
C132	Maury silt loam	40- 60	117	61.8	45.5	3.19	2.16	4.9

From the data in table 7 it is apparent that the acid-soluble boron is concentrated in the colloid. The values are from 7.5 to 1.6 times higher in the colloid than in the whole soil. Since the particle size of the colloids separated by the centrifuge ($<0.3\mu$) differs from that estimated in mechanical analysis ($<2.0\mu$), the percentage of acid-soluble boron in the soil cannot be calculated from soil data. In a sample of the Havre silt loam (C3002), however, colloid and silt plus sand were separated by mechanical analysis procedure and the fractions were found to contain 85 and 24 p. p. m. boron, respectively. Two-thirds of the acid-soluble boron is therefore in the 35 percent of the soil less than 2μ in diameter. From the boron content of the centrifuged colloid (105 p. p. m.) it is apparent that even within the 2μ fraction the finer particles have a higher concentration of boron.

The colloidal fraction of the soil is a far more homogenous body than the whole soil, and it is therefore permissible to attempt to correlate a minor element, such as boron, with some of the other chemical elements present. Mention has been made of the effects of liming on depressing the availability of boron and of the very nearly insoluble nature of the magnesium boron compound, boracite. It can be seen that there is a very general relation between the boron content of the colloids and the calcium and magnesium content.

The uniform boron content of the Havre clay and Sharkey clay colloids would indicate a uniformity of boron in the colloids of the same soil profiles. There is also not much difference in the two members of the Shelby profile. The two members of the Maury silt loam and Carrington loam profiles, however, are greatly different in boron content. The lower member of the Maury profile has a much higher phosphate content than the upper member, and there may have been much difference in the boron contents of the parent materials forming these layers. In the light of what has been stated regarding the unavailability of boron in heavily limed soils, one would expect the colloids in the lower horizons of alkaline reaction to be higher than the boron content of horizons above having an acid horizon. This expectation is borne out in the Carrington profile, but the difference in boron content of the Shelby profile is small though in the right direction. Chemical properties of colloids high in lime and magnesium and the relative insolubility of calcium and magnesium borates would lead to the generalization that soil colloids of a high pH would be high in boron. In general, this generalization is supported by the data. The Maury, Miami, and lower Shelby are exceptions to this generalization. The uneven distribution of boron in the parent materials probably explains the failure of the generalization.

Soils low in colloid may be expected to be low in available boron, whereas fine-textured soils will usually have an abundant supply provided the parent material was not deficient. Evidence from other sources supports this conclusion. Recovery by leaching of boron added to soils is more difficult from heavy soils (*32*). Added boron compounds are more likely to cause toxicity to plants on sandy soils than on clays (*23*). Shales, which are formed from the fine sedimentary material, are higher in boron than most other rocks (*27*). The acidity and colloid content of the soil, therefore, seems to play significant roles in determining the acid-soluble boron content.

The effect of the chemical composition of the soil, as expressed by the molecular ratios of the colloid, is not so clear. Average boron content increases fairly regularly with increasing molecular ratio of silica to alumina plus iron oxide, and with decreasing ratio of silica to total bases. Within a profile, however, the ratios are usually quite constant, although the amount of boron may vary widely. All three are largely determined by climatic conditions, the effect of which parallels their variation with each other. Hence, the apparent relation between them probably exists because all three are functions of the same factor. The direct change of boron content with ratio of silica to sesquioxides indicates that boron is not retained by the soil in a highly insoluble iron compound as are the elements, arsenic and selenium. The change in average acid-soluble boron with silica-total base ratio is evident (table 5) in that with decreasing quantities of bases (increase of silica-total base ratio) the acid-soluble boron also decreases markedly. Decrease in bases also accompanies increased acidity as shown by the pH values.

WATER-SOLUBLE BORON

Water-soluble boron was determined in only a few representative soils from humid areas, since, in these soils, water-soluble boron compounds do not accumulate, and differences between them are relatively small.

In areas of low rainfall in the Western States, soluble boron compounds may accumulate in soils in sufficient quantity to cause injury to plants. In desert regions, soluble borates may be concentrated by evaporation of natural drainage water, whereas in cultivated areas irrigation water may add boron to the soil. Through the cooperation of C. S. Scofield, of the Division of Irrigation Agriculture, samples of desert soils from Fallon, Nev., and of irrigated orchard soils from California were obtained. In table 8 data for water-soluble boron are compared with those for acid-soluble and total boron. Soils from humid areas described in previous tables are listed only by the series name.

In the eastern and middle western soils formed under a humid climate, water-soluble boron ranges from 0.3 to 2.5 p. p. m., with an average of 1.04. Topsoils generally contain considerably more water-soluble boron than the lower horizons. There seems to be no general relation between water-soluble boron and either acid-soluble or total boron.

TABLE 8.—*Relation of water-soluble, soluble, and total boron in certain soils*

SOILS FROM HUMID AREAS

Laboratory sample No.	Soil type and location	Remarks	Depth	Water-soluble boron	Acid-soluble boron	Total boron
			Inches	*P.p.m.*	*P.p.m.*	*P.p.m.*
C4043	Brookston silty clay loam		0- 6	2.5	28.2	42
10084	Carrington loam		13- 22	.5	13.4	25
C4067	Clyde silty clay loam		0- 8	1.5	44.0	46
C4068			8- 20	.8	43.2	46
C4071			38- 66	.3	64.8	73
C4594	Hagerstown stony loam		0- 4	.6	5.8	60.4
C4928	Huntington silt loam		0- 8	.5	26.4	83
8736	Marshall silt loam		0- 13	2.3	23.8	41
8737			13- 24	.7	22.2	34
8738			24- 45	.8	20.4	25
8739			45+	1.0	12.8	28
C4060	Miami silt loam		0- 2	1.3	10.8	32
C4061			2- 5	.7	11.6	35
C2108	Sharkey clay		0- 6	1.0	37.0	40

TABLE 8.—*Relation of water-soluble, soluble, and total boron in certain soils*—Con.

SAMPLES FROM CALIFORNIA

Laboratory sample No.	Soil type and location	Remarks	Depth	Water-soluble boron	Acid-soluble boron	Total boron
			Inches	*P.p.m.*	*P.p.m.*	*P.p.m.*
C5758	Virgin Aiken clay loam, Paradise, Butte Co.	Irrigated with water containing 2-3 p. p. m. boron.	0- 16	0.5	4.0	11
C5759	Yolo sandy loam, Paradise, Butte Co.	do	0- 36	2.5	24.6	29
C5760	Yolo sandy loam, Woodland, Yolo Co.	Not irrigated	0- 30	.6	21.4	24
C5761	Rincon loam, Hollister, San Benito Co.	Irrigated with water containing boron.	0- 6	2.2	11.4	16
			6- 30	1.4	11.6	16
			30- 80	1.6	14.4	16
C5764	Rincon loam, San Benito Co.	Not irrigated	0- 6	1.1	12.4	19
C5765			6- 30	1.1	14.0	15
C5766			30- 60	1.4	14.4	15
C5767	Yolo loam, Santa Paula, Ventura Co.	Boron injury to lemons from irrigation water.	0- 30	1.3	13.8	20
C5768	Rincon loam, Santa Paula, Ventura Co.	do	0- 30	1.8	10.2	13
C5769	Yolo fine sandy loam, Santa Paula, Ventura Co.	do	0- 30	1.5	20.4	28
C5770	Antioch clay loam, Grayson, San Joaquin Co.	Healthy peach trees	0- 30	1.2	22.4	25
C5771	Do	Possible boron injury to peach trees.	0- 30	13.5	33.2	39
C5772	Sierra sandy loam, Riverside.	Orange trees irrigated since 1933 with 1 p. p. m. boron in water.	0- 6	3.1	7.4	11
C5773			6- 30	1.9	5.8	10
C5774	Do	Unirrigated, under native vegetation.	0- 6	.7	4.0	7
C5775			6- 36	.4	3.0	10
C5776	Redding gravelly loam, Kearney Mesa, San Diego Co.		0- 18	1.2	12.0	27
			18- 24	.9	12.2	23

SAMPLES FROM FALLON, NEV. (AT OR NEAR NEWLANDS EXPT. STA.)

Laboratory sample No.	Soil type and location	Remarks	Depth	Water-soluble boron	Acid-soluble boron	Total boron
B17917	Alkali Flat, Rattlesnake Hill.	2 mi. NE of Fallon	0- 6	31.4	76.8	76
			24- 42	47.6	75.4	83
	Desert Plaza, west of experiment station:					
C5751	Impervious clay	A large, barren flat, NW¼ of NW¼ sec. 4, T. 17 N., R. 28 E., water at 12 ft.	0- 24	5.8	27.4	27
C5752	Coarse sand		24- 45	1.4	8.4	11
C5753	Fine sand		46- 84	.4	5.0	8
C5754	Clay		84-102	2.4	13.4	12
C5755	Fine sand		102-108	1.1	7.6	12
C5756	Clay		108-120	1.6	15.2	17
C5757	Fine sand		120-140	.7	10.8	13
	Virgin sandy soil on Swingle Bench:					
C5743	Fine sand	Water table below 40-50 ft	0-144	4.3	11.8	16
B17911	"Z" series, plots 21 and 22	Not under cultivation	0- 6	44.0	60.8	64
B17912			36- 48	14.0	19.2	20
B17913	"Z" series, plots 9 and 0	do	0- 6	127	137	133
B17914			30- 48	51.4	74.6	75
B17915	"S" series, plot 1	Very unproductive, undergoing reclamation.	0- 6	41.6	60.4	60
B17916			30- 48	42.8	62.4	61
	"A" series, plot 25, sandy area:					
C5748	Fine sand	Irrigated for 4 years; produced sweetclover and alfalfa; water at 9 ft.	0- 48	.5	6.8	10
C5749	Sand and clay		48- 60	.8	9.6	12
C5750	Coarse sand		60-108	.2	2.8	9
	"Y" series, plot 4:					
C5744	Sand	Fairly heavy soil, irrigated for 30 years, producing alfalfa and oats; water at 6 ft.	0- 8	3.1	12.6	15
C5745	Clay		8- 30	9.6	24.8	22
C5746	Coarse sand		30- 48	.9	4.2	9
C5747	Heavy clay		48- 96	30.0	43.2	42

The California soils are generally inherently low in boron. The fact that added boron from irrigation water tends to accumulate in these soils suggests that they are developed from boron-poor material. The 21 samples average 1.95 p. p. m. water-soluble, 14.1 p. p. m. acid-soluble, and 18.7 p. p. m. total boron. The 11 irrigated soils contain 2.84, 16.7, and 20.3 p. p. m., respectively, of water-soluble, acid-soluble, and total boron, as compared with averages of 0.87, 10.8, and 16.8 p. p. m. in the nonirrigated soils. Before irrigation, about two-thirds of the total is acid-soluble, while water-soluble boron content is about the same as in the soils of other regions. Much of the boron added by irrigation is retained by the soil in a readily soluble form, thereby considerably increasing the water-soluble content. Acid-soluble and total boron increase but slowly; the Antioch clay loam, with 13.5 p. p. m. water-soluble, still contains less acid-soluble than the Clyde or the Sharkey. Since all of the added boron remains acid-soluble, the ratio of acid-soluble to total boron likewise slowly increases.

The boron status of the Nevada soils is somewhat similar; here, however, added boron has come from natural waters, and because of lower rainfall and longer time of addition, has accumulated in much higher concentrations. The original boron content was probably low. As boron was added by drainage waters and concentrated by evaporation, most of it was retained by the clay layers, the sands holding but little. Much of it remained water-soluble, although some was fixed by the soil and is acid-soluble but water-insoluble. Essentially all the boron in the clays is acid-soluble; the sands contain some boron in resistant minerals.

Two of the virgin soils are fairly low in boron. The Plaza profile, C5751 to C5757, is topped by a very impervious clay layer which protects it and the lower layers from leaching. The bench soil, C5743, on the other hand, is porous and has a low water table, letting water sink through.

Irrigation on the Fallon soils, in contrast with the California orchard soils, washes out the boron compounds and makes the soils productive. Samples B17911-16 are representative of the original uncultivated, very unproductive soil of the Newlands Experiment Station. Boron content is high and half or more is water-soluble, whereas essentially all is acid-soluble. In a sandy area, C5748–50, irrigation and cultivation for 4 years has removed most of the soluble boron, leaving the soil low in all forms of boron. A heavier soil, C5744-47, retains more boron even after 30 years of cultivation. Clay layers are again the highest and still contain considerable water-soluble boron, which is now probably in equilibrium with irrigation and ground water.

MISCELLANEOUS DATA

Boron-Deficient Soils From West Virginia

In certain orchards near Charles Town, W. Va., Ben Davis apples, grown on Hagerstown soil residual from limestone, developed "internal cork" which rendered them unfit for sale.[6] Addition of borax to the soil prevented the disease. The same variety of apples grown on the nearby Berks soil, formed from shale, showed no evidence of internal cork. A number of samples of soils and of apple leaves and immature fruit were collected from these orchards and supplemented by similar samples from an orchard near Hancock, Md., where no internal cork was found. Boron content of these samples is given in table 9. Data for leaves and fruit follow those for the soil on which they were grown. The varieties of apples other than Ben Davis showed no evidence of boron deficiency.

[6] Oral communication from J. R. Magness, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry.

TABLE 9.—*Boron content of certain orchard soils and of leaves and fruit of apple trees*

SAMPLES FROM HIGGS ORCHARD, 1 MILE WEST OF CHARLES TOWN, W. VA.

Laboratory sample No.	Material	Depth of soil	Acid-soluble boron in soil	Boron in air-dry vegetation
		Inches	*P. p. m.*	*P. p. m.*
C4594	Hagerstown stony loam, no boron added	0–4	5.8	
C4595		4–12	6.0	
C4596		12–26	12.8	
C4597		26–30	11.0	
C4844	Ben Davis apple leaves			18
C4845	Ben Davis apples, green			11

SAMPLES FROM JEFF-COOPERAGE ORCHARD, 3 MILES NORTH OF CHARLES TOWN, W. VA.

Laboratory sample No.	Material	Depth of soil	Acid-soluble boron in soil	Boron in air-dry vegetation
C4598	Hagerstown stony loam, ¾ pound borax per tree added	0–4	7.2	
C4599		4–12	13.4	
C4600		12–24	12.2	
C4601		24–48	7.8	
C4846	Ben Davis apple leaves			34
C4847	Ben Davis apples, green			44
C4602	Hagerstown stony loam, no boron added	0–04	6.0	
C4603		4–12	7.6	
C4604		12–20	13.0	
C4605		20–24	14.0	
C4848	Stayman Winesap apple leaves			21
C4849	Stayman Winesap apples, green			12

SAMPLES FROM FAIRVIEW ORCHARD, 3 MILES SOUTHEAST OF MARTINSBURG, W. VA.

Laboratory sample No.	Material	Depth of soil	Acid-soluble boron in soil	Boron in air-dry vegetation
C4591	Berks shale loam	0–4	18.8	
C4592	No boron added	4–12	21.0	
C4850	Stayman Winesap apple leaves			19
C4851	Stayman Winesap apples, green			10
C4852	York Imperial apple leaves			17
C4853	York Imperial apples, green			5

SAMPLES FROM TONOLOWAY ORCHARD, HANCOCK, MD.

Laboratory sample No.	Material	Depth of soil	Acid-soluble boron in soil	Boron in air-dry vegetation
C4963	Shale soil	0–6	57	
C4964		8–12	64	
C4961	Ben Davis apple leaves			30
C4962	Ben Davis apples, green			19
C4967	Shaley clay	0–8	57	
C4968		8–18	61	
C4969		24–30	63	
C4965	Ben Davis apple leaves			33
C4966	Ben Davis apples, green			23
C4972	Shale soil	0–6	57	
C4973		18–24	53	
C4974		48	115	
C4970	Ben Davis apple leaves			28
C4971	Ben Davis apples, green			17
C4975	Shaley soil	0–6	70	
C4976		6–18	60	
C4973A	Stayman Winesap apple leaves			27
C4974A	Stayman Winesap apples, green			12
C4979	Shaley soil	0–6	36	
C4980		18–24	68	
C4977	York Imperial apple leaves			40
C4978	York Imperial apples, green			24

The Hagerstown soil is low in acid-soluble boron in comparison with both the shale soils and the general average of all soils in table 6. The Berks shale loam has a boron content about average, and the shale soils from Hancock are exceedingly high. Total boron in the Hagerstown is about 60 p. p. m. (table 3) and in the Berks shale loam about 50 p. p. m. Both are high, but in the Berks shale loam about one-half is acid-insoluble, whereas in the Hagerstown nine-tenths of the boron in the topsoil is stored in resistant mineral and rock particles. One of the shale soils near Hancock, Md., C4974, contained 126 p. p. m. total, of which 115 is acid-soluble, the highest in both categories for any soil except one from Nevada.

With one exception, the boron content of the leaves is higher than that of the green apples from the same tree. On Hagerstown stony loam, Ben Davis leaves contained 18 p. p. m. and apples 11, in comparison with 30 and 19 p. p. m., respectively, on shale soil and 34 and 44 p. p. m. on Hagerstown treated with borax. Healthy Ben Davis trees have about twice as much boron in leaves and fruit as those producing corky apples. The Stayman Winesaps varied but little in boron content on three different soils, averaging 22 p. p. m. in the leaves and 12 in the apples, while the York Imperial contained more than twice as much boron on soil of 52 p. p. m. average acid-soluble boron as on a soil with 20 p. p. m. Of the healthy trees, the Ben Davis are highest in boron, 29 p. p. m. in leaves and 23 in fruit; York Imperial next with 28 and 14 p. p. m., respectively, and the Stayman Winesap the lowest, 23 and 11 p. p. m. The high boron requirements of the Ben Davis probably explains why that variety alone showed injury from boron deficiency on Hagerstown soil.

Boron-Deficient Soils From Oregon

Powers and Bouquet at the Oregon Experiment Station have demonstrated that many crops, alfalfa, beets, celery, etc., are afflicted by boron-deficiency diseases on several Oregon soils.[7] A number of samples of Oregon soils and plants were supplied by W. L. Powers, of the Oregon station. The results obtained from the examination of these samples are given in table 10.

All of the soils are low in acid-soluble boron; the 20 samples average 5.5 p. p. m., or only one-third of the average for the United States. The very low content of the peat demonstrates again the ready removal of boron from organic matter. The slightly lower boron value for the topsoil of the Chehalis silty clay loam from the turnip field (C4731), compared with a nearby virgin soil, may represent boron removed by crops (C4734). The total boron content of the virgin Chehalis silty clay loam is about 15 p. p. m. (table 3), of which half is acid-insoluble.

Data on four alfalfa samples are given; two with "yellows," or yellowtop, contain 10 and 16 p. p. m. boron, while two healthy samples have 17 and 55 p. p. m. Celery grown on peat was affected by "scratch" and took up 30 p. p. m. boron; when borax was added to the peat it produced healthy celery containing 52 p. p. m. Likewise, beets showed "canker" on peat and on Newberg loam, while boron-treated peat produced good beets with a higher boron content.

[7] Bouquet, A. G. B., and Powers, W. L. CELERY STEM CRACK AND THE USE OF BORON IN ITS CONTROL. Oreg. Agr. Expt. Sta. Cir. of Inform. 194, 4 pp., illus. 1939. [Mimeographed.]
Powers, W. L., and Bouquet, A. G. B. USE OF BORON IN CONTROLLING CANKER OF TABLE BEETS. Oreg. Agr. Expt. Sta. Cir. of Inform. 195, 6 pp., illus. 1939. [Mimeographed.]

TABLE 10.—*Boron content of certain Oregon soils in relation to boron-deficiency symptoms*

Laboratory sample No.	Description of sample	Depth	Boron in air-dry vegetation	Acid-soluble boron in soils
		Inches	*P. p. m.*	*P. p. m.*
C4330	Willamette silty clay loam (old alluvial soil), plat 34, Oregon station, Corvallis, Oreg.	0–8		7.2
C4331		8–18		8.2
C4332		18–36		7.8
C4333		36–50		5.0
C4324	Alfalfa, showing "yellow top," from Willamette green alfalfa,		10	
C4325	from boron-treated plat at Willamette		17	
C4337	Newberg silt loam (recent alluvial soil), NW¼ sec. 11, T. 10 S., R. 3 W., Willamette meridian, Oreg.	0–8		6.2
C4338		8–18		3.4
C4339		18–36		4.8
C4340		36–54½		5.0
C4328	Roots of table beets, showing "canker," or "break-down," from Newberg		19	
C4341	Willow sedge peat (recent, from Lake Labish), NE¼ sec. 31, T. 6 S., R. 2 W., Willamette meridian, Oreg.	0–10		1.4
C4342		12–24		1.3
C4343		24–48		1.8
C4326	Celery, showing "scratch," from peat		30	
C4327	Celery, without "scratch," from peat plus 20 lbs. borax per acre.		52	
C4320	Roots of table beets showing "canker," from peat		14	
C4423	Roots of table beets, without canker, from boron-treated peat		20	
C4423	Tops of table beets, without canker, from boron-treated peat		61	
C4334	Salkum clay loam (old residual soil), NE¼ sec. 24, T. 12 S., R. 3 W., Willamette meridian, Oreg.	0–8		4.2
C4335		8–20		3.9
C4336		20–36		4.0
C4731	Chehalis silty clay loam (alluvial soil), from turnip field, Steinmetz ranch, Chitwood, Oreg.	0–8		6.8
C4732		8–18		6.6
C4633		18–36		9.8
C4729	Bortfeld turnips with possible injury from boron deficiency	Roots	20	
C4730		Tops	23	
C4734	Chehalis silty clay loam, virgin soil, near above samples	0–8		9.0
C4735		8–18		6.8
C4736		18–36		10.0
C4415	Normal alfalfa, experiment station, Moro, Oreg.		55	
C4489	Alfalfa with "yellows," Northport, Wash.		16	
C4488	Leaves from "cracked" broccoli		19	

BORON CONTENT OF ALFALFA SAMPLES

Injury to alfalfa from boron deficiency is widespread. In reporting it in Connecticut, Brown (*11*) gave the boron content of "yellowed" alfalfa as 21 p. p. m. in the leaves and 16 in the stems. Green alfalfa, grown on soil treated with 20 pounds of borax per acre, contained 62 and 22 p. p. m. in leaves and stems. Table 11 shows the boron content of 12 samples of alfalfa, including both stems and leaves.

The low content of the alfalfa from the check plots at the Sandhill Experiment Station indicates boron deficiency. Addition of 5 pounds of borax per acre doubled the boron in the plant, while larger doses caused small additional increases in the plant content. Cecil clay, low in boron, produced a poor stand of alfalfa with "yellows" in the second cutting at Brown Summit, N. C., while on the boron-rich Huntington silt loam at Elliston, Va., the alfalfa was excellent in quality and yield. The lowered content of the second cuttings confirms the observation that boron deficiency is less likely to occur in the first than in later cuttings. The low concentration of boron in the Huntington alfalfa is difficult to explain, but the results have been carefully checked.[8] It has been noted that in the East alfalfa grows best on soils formed from limestone or, as the Huntington silt loam, from limestone alluvium. Such soils may be low in acid-soluble boron, e. g., the Hagerstown stony loam, and the content of the

[8] Private communication from L. V. Wilcox, Division of Irrigation Agriculture, Bureau of Plant Industry.

alfalfa is much less than the 40 to 50 p. p. m. expected in normal alfalfa. The boron content of 69 p. p. m. indicates that the "yellows" of the Idaho alfalfa is not due to boron deficiency but to some other cause.

TABLE 11.—*Boron content of alfalfa with associated data*

Laboratory sample No.	Description of sample	Boron in air-dry vegetation	Acid-soluble boron in soils
SANDHILL EXPERIMENT STATION, COLUMBIA, S. C.[1]			
		P. p. m.	*P. p. m.*
C6548	Norfolk sand from check plot, 0-12 in.		1.0
C6549	2 tons lime added, 12-24 in.		1.6
C5613	Alfalfa from check plot	13	
C5314	do	15	
C5614	Alfalfa, 5 lbs. borax per acre added	26	
C5615	Alfalfa, 10 lbs. borax per acre added	32	
C5633	Alfalfa, 15 lbs. borax per acre added	34	
C5616	Alfalfa, 20 lbs. borax per acre added	39	
BROWN SUMMIT, N. C.			
C4881	Cecil clay, 0-9 in.		4.4
C4882	Cecil clay, 9-18 in.		6.0
C4883	Cecil clay, 18-30 in.		5.2
C4884	Cecil clay, at 36 in.		3.8
C4880	Alfalfa, first cutting	17	
C4879	Alfalfa, second cutting, least injury	17	
C4878	Alfalfa, second cutting, maximum injury	13	
ELLISTON, VA.			
C4928	Huntington silt loam, 0-8 in.		26.4
C4929	Huntington silt loam, 8-24 in.		27.2
C4930	Huntington silt loam, at 30 in.		28.6
C4926	Alfalfa, first cutting	19	
C4927	Alfalfa, second cutting	15	
RAFT RIVER, IDAHO			
B20603	Gray silt loam, 0-10 in.		41.0
B20604	Alfalfa with "yellows"	69	

[1] Samples furnished by H. L. Westover, Division of Forage Crops and Diseases, Bureau of Plant Industry.

GENERAL REMARKS

Obviously the determination of what constitutes an adequate quantity of boron in soils will have to await fuller knowledge of the needs of various crops and the degree of availability of the different forms of boron. Whether soils contain toxic quantities depends not only on the crops grown but on other considerations. Nevertheless, the information available warrants certain general statements.

From the data presented, an acid-soluble boron content of about 10 p. p. m. in the soil seems to be the minimum to insure sufficient boron for healthy plant growth. On soils with less than 10 p. p. m., some plants are very likely to show boron deficiency. This division is purely arbitrary and in practice would be influenced by other factors. Boron requirements of different plants and even of varieties of the same plant may vary widely. In highly alkaline or heavily limed soils, boron availability may be rendered too low to meet plant needs even though the acid-soluble content is fairly high. Despite its limitations, such an arbitrary minimum value is useful in delimiting areas of possible boron deficiency.

There are three large regions in the United States in which the soils seem likely to be deficient in boron. The Atlantic coast from Maine to Florida and west approximately to the Appalachian Mountains, and the Gulf coast to Texas form one area. Reports of boron deficiency from the Maritime Provinces (*50*) and from Ontario (*40*) indicate that it extends into Canada. The soils are largely Podzols and Red and Yellow Podzolic, and tend to be sandy and rather acid. They owe their low soluble boron content mainly to intensive leaching. Alluvial soils of the Mississippi and perhaps of other rivers, within this region, appear to contain abundant boron.

Across northern Michigan, Wisconsin, and Minnesota there is a broad strip of Podzols. Although only one profile sample from this area has been examined, the low boron content of other members of this highly leached group suggests that these soils are likely to be deficient in boron.

The third area of low boron soils is in the States of the Pacific coast and the Pacific Northwest. The data here presented on California, Oregon, and Washington soils, together with reports of deficiency from Washington (*15*), Idaho (*17*), and British Columbia (*34*), indicate the extent of this area. Here the parent material is evidently low in boron. In parts of this area, where low rainfall permits accumulation of soluble borates in the soil and where irrigated with water containing boron, toxicity is more likely than deficiency.

In the remainder of the United States (most of the land between the Alleghenies and the Rockies) boron deficiency should be unlikely except perhaps in occasional small areas of peats, mucks, or other soils developed under a high water table. These generalizations are, however, subject to many exceptions. Some, or even a large part, of the soils in the areas described as boron deficient may contain an ample supply of boron. Liming or intensive cultivation of high-boron crops on any soil may decrease the available boron below plant requirements.

Natural boron toxicity is unlikely except in arid regions where soluble salts may accumulate in the soil. The shale soils of Hancock, Md., with as much as 115 p. p. m. acid-soluble boron, the highest found in soils in a humid climate, give no evidence of toxicity. Under normal rainfall, natural water-soluble boron is probably so readily removed that it cannot concentrate in sufficient amount to injure plants. The maximum quantity found in humid soils was 2.5 p. p. m. in the Brookston silty clay loam series.

If boron compounds should be applied, intentionally or otherwise, in excessive amounts, they are not likely to cause permanent toxicity in the soils previously deficient. In these soils, usually acid and low in colloid, much of the boron remains in a water-soluble form readily available to the soil solution. It may therefore be removed by leaching. In heavier, more alkaline soils, much of the boron is precipitated or adsorbed by the colloid in a relatively insoluble form and is more slowly given up to the soil solution and removed by leaching.

SUMMARY AND CONCLUSIONS

Methods are described for the determination of phosphoric acid-soluble, total, and water-soluble boron in soils.

Boron was detected in all of about 300 soil samples. In soils formed under normal rainfall, total boron ranged from 4 to 88 p. p. m. with an average of 30.0. Acid-soluble boron, or presumably the maximum available boron, varied from 0.4 to 64.8 and averaged 17.1 p. p. m., which represents 50 percent of the total. About 1 p. p. m. is water-soluble. Acid-insoluble boron, or that stored in resistant minerals, varied from 0 to 61 p. p. m., with an average of 13.9. Assuming all the acid-insoluble boron to be present as tourmaline, the maximum value represents a concentration of about 0.2 percent of that mineral. Desert soils contained as much as 133 p. p. m. of total boron, essentially all of it soluble in total water and acid while a soil derived from pegmatite contained 98 p. p. m. of boron, of which the major portion (93 p. p. m.) is acid-insoluble.

The amount of boron is dependent on the soil parent material and on weathering. Soils derived from alluvium, limestone, shale, and glacial drift are high in boron, those from igneous rock and unconsolidated sediment low. Leaching tends to decrease acid-soluble and concentrate acid-insoluble boron.

Podzols, Half Bog, muck, and Red and Yellow Podzolic soils are low in acid-soluble and relatively high in acid-insoluble boron. Alluvial, Gray-Brown Podzolic, Prairie, Chestnut, Brown, and Chernozem soils are high in boron, most of it acid-soluble.

Acid-soluble boron increases with increasing colloid content, is considerably concentrated in the colloid with respect to other portions of the soil, and is uniform in the colloid throughout the profile. Acid-soluble boron increases regularly with increasing soil pH. The kind of colloid has no significant relation to the boron content.

California soils are generally low in boron, due to parent material. Irrigation with water containing boron increases water-soluble boron rapidly; acid-soluble and total slowly. Desert soils from Fallon, Nev., are very high in boron, most of it water-soluble, which is removable by irrigation.

Injury to apples, alfalfa, celery, and beets from boron deficiency in Oregon, West Virginia, and North Carolina is associated with low boron content of the soil.

Three large areas in the United States are likely to show boron deficiency: Atlantic and Gulf coasts from Maine to Texas; northern Minnesota, Wisconsin, and Michigan; and California and the Pacific Northwestern States.

Natural boron toxicity is unlikely except in arid regions. Toxicity from added boron is more likely on acid, sandy soils, often previously boron-deficient.

LITERATURE CITED

(1) Alexander, Lyle T., Byers, Horace G., and Edgington, Glen.
1939. A CHEMICAL STUDY OF SOME SOILS DERIVED FROM LIMESTONE. U. S. Dept. Agr. Tech. Bul. 678, 27 pp.

(2) Askew, H. O., Thomson, R. H. K., and Chittenden, E.
1938. EFFECT OF BORAX TOP-DRESSING ON BORON STATUS OF SOIL AND FRUIT. New Zeal. Jour. Sci. and Technol. 20: 74A–78A.

(3) ——— Thomson, R. H. K., and Kidson, E. B.
1937. THE BORON STATUS OF NEW ZEALAND FRUIT SOILS. New Zeal. Jour. Sci. and Technol. 18: 789–796.

(4) Bertrand, Gabriel.
1903. LES ENGRAIS COMPLÉMENTAIRES. Chem. Ztg. 27: 613–614.

(5) ———
1912. SUR LE ROLE DES INFINIMENT PETITS EN AGRICULTURE. 8th Internatl. Cong. Appl. Chem. 28: 30–48.

(6) BERTRAND, GABRIEL, and AGULHON, H.
1912. SUR LA PRÉSENCE NORMALE DU BORE CHEZ LES ANIMAUX. [Paris] Acad. des Sci. Compt. Rend. 155: 248–251.
(7) ——— and SILBERSTEIN, LAZARE.
1938. SUR LA RÉPARTITION DU BORE DANS LES ORGANES DU LIS BLANC. [Paris] Acad. des Sci. Compt. Rend. 206: 796–799.
(8) ——— and SILBERSTEIN, LAZARE.
1939. SUR LA TENEUR DU SOL EN BORE. [Paris] Acad. des Sci. Compt. Rend. 208: 1453–1456.
(9) BOBKO, E. V., MATVEEVA, T. V., DOUBACHOVA, T. D., and PHILIPPOW, A. I.
1936. RECHERCHES SUR L'ABSORPTION DU BORE PAR LES SOLS. Ann. Agron. [Paris] 6: [691]–701, illus.
(10) BRANDENBURG, E.
1931. DIE HERZ- UND TROCKENFÄULE DER RÜBEN ALS BORMANGEL–ERSCHEINUNG. Phytopath. Ztschr. 3: [499]–517, illus.
(11) BROWN, B. A.
1940. BORON DEFICIENCIES IN CONNECTICUT. Science 91: 338.
(12) BROWN, B. E.
1922. EFFECT OF BORAX IN FERTILIZER ON THE GROWTH AND YIELD OF POTATOES. U. S. Dept. Agr. Bul. 998, 8 pp., illus.
(13) BROWN, IRVIN C., and BYERS, H. G.
1938. CHEMICAL AND PHYSICAL PROPERTIES OF CERTAIN SOILS DEVELOPED FROM GRANITIC MATERIALS IN NEW ENGLAND AND THE PIEDMONT, AND OF THEIR COLLOIDS. U. S. Dept. Agr. Tech. Bul. 609, 56 pp.
(14) BYERS, HORACE G., ALEXANDER, LYLE T., and HOLMES, R. S.
1935. THE COMPOSITION AND CONSTITUTION OF THE COLLOIDS OF CERTAIN OF THE GREAT GROUPS OF SOILS. U. S. Dept. Agr. Tech. Bul. 484, 39 pp.
(15) CAMPBELL, LEO, HEALD, F. D., and JONES, L. K.
1937. ETIOLOGY AND PREVENTION OR CONTROL OF DISEASES OF SUGAR BEETS. Wash. Agr. Expt. Sta. Ann. Rpt. 47: 56.
(16) CLARKE, FRANK WIGGLESWORTH, and WASHINGTON, HENRY STEPHENS.
1924. THE COMPOSITION OF THE EARTH'S CRUST. U. S. Geol. Survey Prof. Paper 127, 117 pp.
(17) COLWELL, WILLIAM E., and BAKER, G. ORIEN.
1939. STUDIES OF BORON DEFICIENCY IN IDAHO SOILS. Amer. Soc. Agron. Jour. 31: 503–512, illus.
(18) CONNER, S. D., and FERGUS, E. N.
1920. BORAX IN FERTILIZERS. Ind. Expt. Sta. Bul. 239, 15 pp., illus.
(19) COOK, F. C.
1916. BORON: ITS ABSORPTION AND DISTRIBUTION IN PLANTS AND ITS EFFECT ON GROWTH. Jour. Agr. Res. 5: 877–890.
(20) ——— and WILSON, J. B.
1918. BORON: ITS EFFECT ON CROPS AND ITS DISTRIBUTION IN PLANTS AND SOIL IN DIFFERENT PARTS OF THE UNITED STATES. Jour. Agr. Res. 13: 451–470.
(21) COOK, R. L.
1940. BORAX AS A CONTROL FOR HEART ROT OF SUGAR BEETS. Better Crops with Plant Food 24 (5): 12–16, 39–46, illus.
(22) DENNIS, R. W. G.
1937. THE RELATION OF BORON TO PLANT GROWTH. Science Prog. 32: 58–69.
(23) EATON, FRANK M.
1935. BORON IN SOILS AND IRRIGATION WATERS AND ITS EFFECT ON PLANTS, WITH PARTICULAR REFERENCE TO THE SAN JOAQUIN VALLEY OF CALIFORNIA. U. S. Dept. Agr. Tech. Bul. 448, 132 pp., illus.
(24) ——— McCALLUM, ROY D., and MAYHUGH, MILES S.
1941. QUALITY OF IRRIGATION WATERS OF THE HOLLISTER AREA OF CALIFORNIA, WITH SPECIAL REFERENCE TO BORON CONTENT AND ITS EFFECT ON APRICOTS AND PRUNES. U. S. Dept. Agr. Tech. Bul. 746, 60 pp., illus.
(25) ——— and WILCOX, L. V.
1939. THE BEHAVIOR OF BORON IN SOILS. U. S. Dept. Agr. Tech. Bul. 696, 58 pp., illus.

(26) GADDUM, L. W., and ROGERS, L. H.
1936. A STUDY OF SOME TRACE ELEMENTS IN FERTILIZER MATERIALS. Fla. Expt. Sta. Bul. 290, 15 pp.
(27) GOLDSCHMIDT, V. M., and PETERS, C. L.
1932. ZUR GEOCHEMIE DES BORS. Gesell. der Wiss. zu Göttingen, Math. Phys. Kl. Nachr. 5: [402]-407, 528-545.
(28) HOLMES, R. S., HEARN, W. E., and BYERS, H. G.
1938. THE CHEMICAL COMPOSITION OF SOILS AND COLLOIDS OF THE NORFOLK AND RELATED SOIL SERIES. U. S. Dept. Agr. Tech. Bul. 594, 34 pp., illus.
(29) JANNASCH, PAUL, and NOLL, FRIEDRICH.
1919. UBER DIE QUANTITSCH BESTIMMUNG DER BORSÄURE. Jour. f. Prakt. Chem. 99: 1-33, illus.
(30) JEFFRIES, C. D., and WHITE, J. W.
1937. SOME MINERALOGICAL AND CHEMICAL CHARACTERISTICS OF A HAGERSTOWN SOIL PROFILE. Soil Sci. Soc. Amer. Proc. 2: 133-141, illus.
(31) KELLEY, W. P., and BROWN, S. M.
1928. BORON IN THE SOILS AND IRRIGATION WATERS OF SOUTHERN CALIFORNIA AND ITS RELATION TO CITRUS AND WALNUT CULTURE. Hilgardia 3: 445-458.
(32) KRÜGEL, C., DREYSPRING, C., and LOTTHAMMER, R.
1937. ANSWASCHVERSUCHE MIT BORATEN. Superphosphat 13: 99-104.
(33) LUCHETTI, G.
1938. RICERCHE SUI TERRENI DELLA ZONA BORACIFERA DI LARDERELLO, I.—IL BORO NEL TERRENO E NELLE PIANTE. Pisa Univ., Facoltà di Agrar., Ann. (n. s.) 14: [177]-195, illus.
(34) MCLARTY, H. R., WILCOX, J. C., and WOODBRIDGE, C. G.
1937. A YELLOWING OF ALFALFA DUE TO BORON DEFICIENCY. Sci. Agr. 17: 515-517.
(35) MIDDLETON, H. E., SLATER, C. S., and BYERS, HORACE G.
1932. PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS. U. S. Dept. Agr. Tech. Bul. 316, 51 pp.
(36) ——— SLATER, C. S., and BYERS, H. G.
1934. THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE SOILS FROM THE EROSION EXPERIMENT STATIONS—SECOND REPORT. U. S. Dept. Agr. Tech. Bul. 430, 63 pp., illus.
(37) MOBERG, E. G., and HARDING, M. W.
1933. THE BORON CONTENT OF SEA WATER. Science 77: 510.
(38) NAFTEL, JAMES A.
1937. SOIL LIMING INVESTIGATIONS: V. THE RELATION OF BORON DEFICIENCY TO OVER-LIMING INJURY. Amer. Soc. Agron. Jour. 29: 761-771, illus.
(39) RADER, LEWIS F., JR., and HILL, W. L.
1938. DETERMINATION AND OCCURRENCE OF BORON IN NATURAL PHOSPHATES, SUPERPHOSPHATES, AND DEFLUORINATED PHOSPHATE ROCKS. Jour. Agr. Res. 57: 901-916, illus.
(40) RAYMOND, L. C.
1938. BROWNHEART OF SWEDE TURNIPS. Ontario Dept. Agr. and Expt. Union, Ann. Rpt. (1937) 59: 45-46.
(41) ROBINSON, W. O., STEINKOENIG, L. A., and FRY, WILLIAM H.
1917. VARIATION IN THE CHEMICAL COMPOSITION OF SOILS. U. S. Dept. Agr. Bul. 551, 16 pp.
(42) ROGERS, L. H., GALL, O. E., GADDAM, L. W., and BARNETTE, R. M.
1939. DISTRIBUTION OF MACRO AND MICRO ELEMENTS IN SOME SOILS OF PENINSULAR FLORIDA. Fla. Agr. Expt. Sta. Bul. 341, 31 pp., illus.
(43) SCHALLER, WALDEMAR T.
1930. BORATE MINERALS FROM THE KRAMER DISTRICT, MOJAVE DESERT, CALIFORNIA. U. S. Geol. Survey Prof. Paper 158: 137-170, illus.
(44) ROTHAMSTED EXPERIMENT STATION.
1921. THE FEEDING OF THE PLANT. Rothamsted Expt. Sta., Harpenden, Rpt. 1921-22: 14-16.
(45) SCHARRER, K., and GOTTSCHALK, R.
1935. ZUR METHODIK DER BESTIMMUNG KLEINSTER MENGEN BORSÄURE. Ztschr. f. Pflanzenernähr., Düngungu. Bodenk. 39: 178-197.

(46) SMITH, G. STANLEY.
1935. THE DETERMINATION OF SMALL AMOUNTS OF BORON BY MEANS OF QUINALIZARIN. Analyst 60: 735–739.

(47) WELLS, ROGER C.
1937. ANALYSES OF ROCKS AND MINERALS FROM THE LABORATORY OF THE UNITED STATES GEOLOGICAL SURVEY 1914–36. U. S. Geol. Survey Bul. 878, 134 pp.

(48) WILCOX, L. V.
1940. DETERMINATION OF BORON IN PLANT MATERIAL, AN IGNITION-ELECTROMETRIC TITRATION METHOD. Indus. and Engin. Chem., Analyt. Ed., 12: 341–343, illus.

(49) WITTSTEIN, and APOIGER, F.
1857. ENTDECKUNG DER BORSÄURE IM PFLANZENREICHE. Ann. der Chem. u. Pharm. 103: 362–364.

(50) WOODBRIDGE, V. G.
1940. THE BORON CONTENT OF SOME OKANAGAN SOILS. Sci. Agr. 20: 257–265.

(51) YOUNG, R. S.
1935. CERTAIN RARER ELEMENTS IN SOILS AND FERTILIZERS, AND THEIR RÔLE IN PLANT GROWTH. N. Y. (Cornell) Agr. Expt. Sta. Mem. 174, 70 pp.

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