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THE BORON CONTENT OF
BRITISH COLUMBIA SOILS AND THE BORON
FERTILIZER VALUE OF TOURMALINE ROCK

by

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ABSTRACT

Part I. The Boron Content of British Columbia Soils

British Columbia soils were analyzed for total and available boron. Peace River soils showed significantly higher total contents than did soils from the rest of the province. Lower Fraser Valley soils were low in total boron.

One hundred and twenty-four surface soils showed available boron contents ranging from 0.0 to 22.0 p.p.m. Lime additions seemed to lower the available boron content of certain Fraser Valley Soils.

Part II. Investigations Concerning the Possibility of Using Tourmaline Rock as a Boron Fertilizer.

A Tourmaline rock supplied by the Consolidated Mining and Smelting Company seemed to offer little value as a boron fertilizer.

PART I.- THE BORON CONTENT OF BRITISH COLUMBIA SOILS

INTRODUCTION

During the past two decades, a great deal of attention has been focused on the role of the so-called minor element, boron, in agriculture. The element, in common with certain others, is unique in that the optimum range in the soil for normal plant growth is both extremely low and very narrow. Thus, while realizing the importance of a sufficiency, one must also bear in mind the possibility of an excess.

The relationship of boron to soil fertility has stimulated much research during recent years in the United States and Canada. Since densely populated European lands have been intensively fertilized, especially with organic matter, boron and other minor element deficiencies have not been so severe as in extensive soil areas of North America, where depletion of nutrients through over-cropping and inadequate fertilization has been the rule rather than the exception.

A study of the element as it occurs in soil involves the determination of several forms, the various proportions of which are closely related to parent material, weathering, and certain other factors.

Several areas in British Columbia are known, or suspected, to possess soils deficient in boron, but the Okanagan Valley is the only one that has been investigated with any degree of thoroughness. It was felt, therefore,

that a general survey in respect to the boron status of British Columbia soils might serve as a valuable contribution towards a better understanding of the problem.

Specifically, the studies reported at this time deal with the concentration of total and available boron in surface and sub-surface soils as well as the effect of total boron, parent material, weathering, and other factors on the supply of the element released for plant growth. Such studies should not only indicate which areas in British Columbia merit more thorough investigation in respect to their boron status, but should also serve to enrich the existing store of knowledge relative to distribution and behaviour of the element in soils.

REVIEW OF LITERATURE

Historical

The presence of boron in the seeds of certain plants was demonstrated by Wittstein and Apoiger (1857) nearly a century ago, and yet its recognition as an essential constituent in plants is relatively recent. Jay (1895), who analyzed many plants grown in solutions and on a wide variety of soils, was perhaps the first to realize that boron is a normal constituent in plant material.

While boron was recommended by Bertrand (1903) as a

supplement to nitrogen, phosphate, and potash, in commercial fertilizers, it was considered only as a stimulatory factor. Not until the work of Warrington (1923), Brenchley and Warrington (1927), and Sommer and Lipman (1926) appeared in literature, was boron recognized as an indispensable nutrient.

During the second decade of the present century, the toxic effect on plants of an excess of boron was pointed out by Cook and Wilson (1918), and this has since been fully demonstrated.

The relationship of boron deficiency to certain plant diseases, such as heart rot of sugar beets, was established by Warrington (1923), Sommer and Lipman (1926), and Brandenburg (1931), etc. Since that time many plant diseases and physiological disorders have been attributed to boron deficiency.

The first recorded use of a boron fertilizer in British Columbia was during the early Twenties at Pemberton Meadows, where the application of boron improved the yield and quality of roots crops. Later, in the Okanagan Valley, McLarty (1936) demonstrated that certain disorders in apples were caused by a boron deficiency. Since then, the use of boron fertilizers in the Okanagan and many other districts throughout the Province has become quite general.

The use of boric acid as a fertilizing material in Europe has been increasing rapidly, so that, by 1938, for

instance, 1800 tons were applied to sugar beet crops alone. Chart I shows how the interest in boron as a fertilizer has increased the world over during the past 10 years as compared with the preceding 70 years.

Boron Minerals

Natural deposits of borates occur in arid regions, and boric acid is present in fumaroles in Tuscany. Tourmaline, however, is the most important mineral source of boron in the soil, and is the only boron-bearing mineral commonly identifiable in soils. It is a complex alumino borosilicate of iron, magnesium, or other base, and contains about 10 per cent of boric oxide B_2O_3 or 3.1 per cent of boron. It may be given the formula $R_9Al_3(BOHF)_2Si_4O_9$ (where $R = H, Al, Mg, Fe, Cr, K, Na$). Small fragments of tourmaline in soils frequently show a bright clean surface and sometimes the characteristic crystal form.

The mineral is described by Bayley (1917) as an isomorphous mixture of several substances occurring as derivatives of the alumino-borosilicic acid. The four groups of tourmalines that are clearly distinguishable are:-

- (1) Alkali tourmalines, which are colourless, red or green, and transparent.
- (2) Iron tourmalines, which are usually dark blue or black, and translucent.
- (3) Magnesium tourmalines, which are yellowish-brown, or brownish, and translucent.

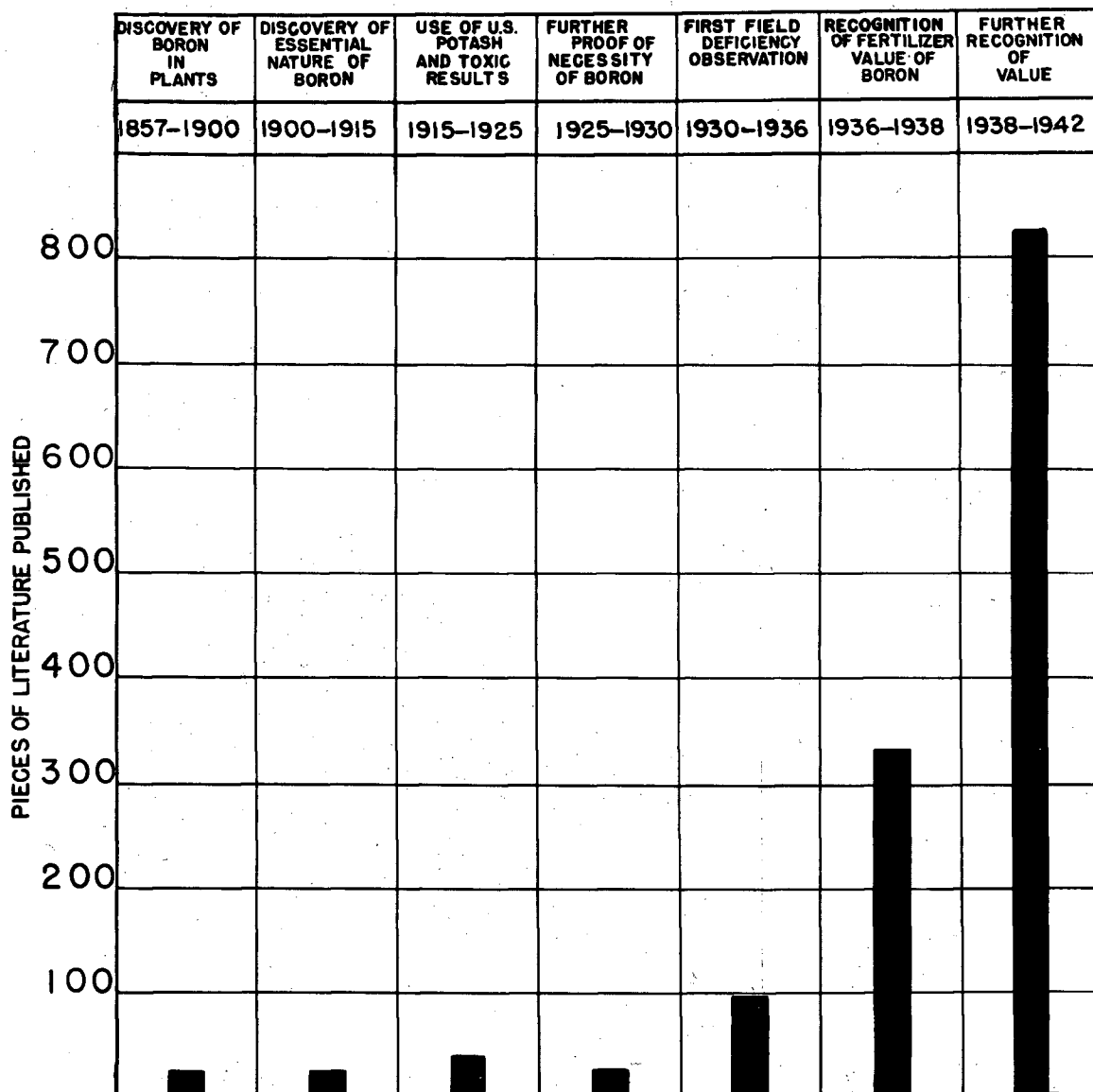


CHART I. THE INCREASED INTEREST IN BORON AS A
FERTILIZER ELEMENT.

Note: This chart originally appeared in a publication of the Pacific Coast Borax Company.

- (4) Chrome tourmalines, which are dark green, black and translucent, or colourless and transparent.

The analyses of these four varieties are presented in Table I. All the tourmalines are extremely stable and very resistant to weathering. Even though a soil may contain a high percentage of the mineral, it is doubtful if any of it would be available to plants.

Robinson, et al (1917), showed the mineral to be widely distributed in rocks and soils of the United States. In British Columbia, at Kimberley, there are immense quantities of a hard, black, cherty rock high in tourmaline, while to the south-east of Hope, near the Skagit River, there is an extensive deposit of pure tourmaline.

Further investigation on minerals containing boron has been made by Merrill (1910), who stated that other borates, while not so common as tourmaline, are of more commercial importance, and merit consideration. There are borax, $\text{Na}_2\text{O} \cdot 2\text{B}_2\text{O}_3 \cdot 10\text{H}_2\text{O}$; colemanite, $2 \text{CaO} \cdot 3\text{B}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$; ulexite, $\text{Na}_2\text{O} \cdot 2\text{CaO} \cdot 5\text{B}_2\text{O}_3 \cdot 16\text{H}_2\text{O}$; and boracite, $\text{MgCl}_2 \cdot 6\text{MgO} \cdot 8\text{B}_2\text{O}_3$. Some of these, such as borax, are often used as minor element fertilizers.

The last mentioned, especially borax, are found throughout the Great Basin region of the Western United States in the San Bernardino counties in California, and also in a portion of south-west Nevada. Some boron salts are commercially extracted from saline waters, while others are obtained from dry lakes, alkali flats, and salt beds.

TABLE I.-

Typical Percentage Compositions of the Four
Tourmalines as Described by Bayley (1917)

	1	2	3	4
SiO ₂	38.07	34.99	37.39	36.56
B ₂ O ₃	9.99	9.63	10.73	8.90
Al ₂ O ₃	42.24	33.96	27.89	32.58
Cr ₂ O ₃	--	--	--	4.32
FeO	0.26	14.23	0.64	--
MnO	0.35	0.06	--	Trace
CaO	0.56	0.15	2.78	0.75
MgO	0.07	1.01	14.09	9.47
Na ₂ O	2.18	2.01	1.72	2.22
K ₂ O	0.44	0.34	0.16	0.13
Li ₂ O	1.59	Trace	Trace	Trace
H ₂ O	4.26	3.62	3.83	3.74
F	0.28	--	Trace	0.06
TiO ₂	--	--	1.19	0.09
TOTAL:	100.29	100.00	100.42	99.70

With the exception of boracite, these less common minerals are quite soluble. It is quite conceivable that some, if not all, are present in normal soils in minute quantities and constitute a source of readily available boron for the plant. Even boracite, being considerably more soluble than tourmaline, would weather in time to liberate the element.

Schaller (1930) has listed no less than 56 known boron minerals.

The Forms of Boron in the Soil

The element, boron, occurs naturally in nearly all soils. This statement 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 (2) the wide distribution of tourmaline. Three forms of the element which are often determined in soils are total, reserve or maximum available, and water soluble.

Total Boron:

The total boron content of soils varies considerably, and a knowledge of such is generally of little value when considering the fraction of the element available to plants. Berger and Truog (1939) state that less than 5 per cent of the total boron is in a soluble form, while Whetstone, et al (1942), found that no definite relationship existed between total and hot-water-soluble boron. However, from a research

standpoint, when an attempt is being made to classify soils in respect to their boron status, a knowledge of the total content is highly desirable.

Twenty-four soils from Europe and Africa, analyzed by Bertrand and Silberstein (1939), contained from 7 to 50 p.p.m. total boron, 75 per cent of them between 10 and 30 p.p.m. Rogers and associates (1939) estimated as much as 100 to 500 p.p.m. total 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. De Turk and Olsen (1941) analyzed some Illinois and Georgia soils and found the total boron to vary from 5 p.p.m. to 52 p.p.m. Dean (1941) found the total content of the element in 20 Hawaiian surface soils to range from 10 to 60 p.p.m. In the soils of the Usbek republic in Russian Turkestan, Zhorikov (1939) found the total boron to range from 10 to 30 p.p.m. Whetstone, et al (1942), determined the total boron of 118 American soils and found the average to be 30 p.p.m. They also showed that, in sandy unconsolidated sediments, the total boron content is high, but is in the form of resistant minerals and nearly all unavailable to plants.

Reserve or Maximum Available Boron:

The reserve or maximum available boron exists in both the inorganic and organic forms. The former is probably the soil boron of greatest agricultural significance. It consists of boron precipitated as inorganic compounds or

adsorbed and chemically combined at or near the surface of the soil particles. This store of boron is in quasi equilibrium with the boron in soil solution, and, though of low solubility, replaces the boron lost from the solution by leaching or absorption by plants. Eaton and Wilcox (1939) showed that soil would furnish boron for 20 or more consecutive leachings. Cook and Wilson (1918) and, later, Eaton, et al (1941), demonstrated that added boron is fixed by the soil. By long continued leaching, however, the latter authors were able to recover practically all of the element added. Krugel, et al (1937), reported recovery of at least 75 per cent of added boron, except when added as insoluble magnesium borate or boracite. Gile (1945) showed that, although soil colloids fixed added boron, they did not fix it in a form unavailable to plants.

Residues of plant and animal materials constitute the major source of reserve boron in the organic form. 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 amounts, should be rather quickly converted by decay into a soluble form available to plants. Reeve, et al (1944), showed that the water-soluble boron in soils was materially increased by the addition of green manures.

Berger and Truog (1945) state that, in Wisconsin, soils having a pH below 7.3 and containing considerable organic matter usually contain adequate supplies of available boron.

Whetstone, et al (1942), considered boron soluble in 85 per cent phosphoric acid to be an index of reserve or potential boron in the soil, and showed that most of it is concentrated in the soil colloid. Consequently, coarse soils, with their low colloidal content, give a low acid-soluble value, and are considered to have a low boron reserve. Fine-textured soils, on the other hand, have a high value. This is supported by the fact that shales, which are formed from fine sediment, usually have a higher boron content than other rocks. Recovery of added boron by leaching from clay soils is usually more difficult than from light, coarse-textured ones.

Water-soluble Boron:

Most of the boron determinations on soils have been designed to estimate that portion of the element soluble in water or readily available to plants. Many different solutions and methods of extraction have been employed. This makes the various data somewhat confusing. Despite this, it has been shown that the range of readily available boron in soils for normal plant growth is a very narrow one. When the supply is insufficient, plants exhibit deficiency symptoms, and when the range is exceeded, toxicity manifests itself. Of course, it can be appreciated that different

crops have different boron requirements. In addition, the optimum level probably varies with the soil type. Eaton and Wilcox (1939) proposed the following rough grouping for concentrations of readily available boron in soils: (1) those that are insufficient to support normal plant growth, usually below 0.1 to 0.5 p.p.m., (2) those that cause injury, usually in excess of 0.5 to 5.0 p.p.m., and (3) the intermediate concentrations that produce normal plant growth.

In Italy, Salto (1939) determined the hot-water-soluble boron of about 100 different soils. The content varied between 0.06 and 1.4 to 1.9 p.p.m. Aqueous extracts of five Russian soils of different great soil groups contained from 0.11 to 0.25 p.p.m. of boron. In New Zealand, Askew, et al (1938), extracted 0.05 to 0.68 p.p.m. from several orchard top soils. Within a profile, the amount of soluble boron decreased with depth. In Hawaii, Dean (1941) found the water-soluble content of surface soils to range from 0.2 to 2.6 p.p.m.

In America, De Turk and Olson (1941) found that the water-soluble boron of Georgia soils ranged from 0.05 to 1.22 p.p.m. Whetstone, et al (1942), found that the average hot-water-soluble boron content of normal soils was about 1 p.p.m., while desert soils contained as much as 133 p.p.m. The authors add that natural boron toxicity is unlikely except in arid regions.

In orchard soils of Northumberland and Durham Counties,

Ontario, Gardiner (1940) found the water-soluble content to vary from 0.04 to 5.65 p.p.m. Representative Okanagan soils of British Columbia, analyzed by Woodbridge (1940), showed a water-soluble boron content of 0.09 to 0.33 p.p.m.

Methods of Analysis

Early analytical methods were chiefly concerned with relatively large amounts of boron in rocks and minerals and were either gravimetric or volumetric. The former consists of converting the boron to methyl borate and then allowing this to react with a weighed amount of calcium oxide. In the ensuing reaction, calcium borate is formed and the increased weight of the lime represents boric oxide (B_2O_3). The volumetric method involves the titration of boric acid with sodium hydroxide in the presence of mannitol. The chemistry of the reaction is not wholly understood, but the premature development of the end point, due to the hydrolysis of the sodium borate, is prevented in the presence of mannitol or glycerol.

At first, modifications of the last mentioned classic procedure were employed for the determination of minute amounts of boron in soils, and even now these are not uncommon. Such modifications have been used by Wilcox (1932), Cook and Millar (1938), Woodbridge (1940), Eaton, et al (1941), and Whetstone, et al (1942), all of whom adopted the volumetric method of Chapin (1908), who determined the element in rocks and minerals. The boron is distilled with methyl alcohol

from a strongly acid, nearly water-free solution as methyl borate. The latter is then decomposed by alkali and the boric acid estimated by titrating electrometrically, or colorimetrically with standard alkali in the presence of mannitol.

At best, however, such adaptations are cumbersome and sometimes inconsistent. More recently, colorimetric spectrographic, and biological methods have been developed, and the use of these, particularly the first named, has become quite general.

Bertrand and Agulhon (1910), who first realized the importance of boron for normal plant growth, used an analytical method which involved the matching of stains produced on tumeric paper by the boron in strong hydrochloric acid solutions of samples under study. This method was modified by Scott and Webb (1932), and, although still somewhat inaccurate, led to the development of colour tests using curcumin, quinalizarin, and other agents.

Cassal and Gerrans (1903) had much earlier developed a method for determining micro-amounts of boron using colour solutions rather than test-papers. However, no further study was made of the Cassal-Gerrans method until Naftel (1939) utilized a modification employed by Gooch (1887) which shortened the procedure considerably. In Naftel's method, the colour reaction occurs when a solution of boric and oxalic acids is evaporated to dryness with curcumin. The

residue is then extracted with ethyl alcohol and an aliquot rendered alkaline with calcium hydroxide evaporated and cooled to room temperature. Then oxalic acid, and either curcumin or an extract of tumeric are added and evaporated to dryness. The residue is taken up in 95 per cent ethyl alcohol, clarified, and compared with standards either visually or by the use of a photoelectric colorimeter.

Feigl and Krumholz (1929), comparing purpurin, alizarin, and quinalizarin, concluded that the last named, which changes from a pink to a bluish hue as the concentration of boron increases, is the most sensitive. This reaction is the basis of the quinalizarin procedure developed almost simultaneously by De Turk and Olson (1941) and Berger and Truog (1939), and later improved by the latter authors (1944). This procedure is generally conceded to be the most accurate and sensitive for determining minute quantities of boron in soils and plants. It entails evaporating an alkali solution containing the boron to dryness followed by gentle ignition to destroy organic matter and nitrates. The ignited residue is taken up in dilute sulphuric acid, and to an aliquot of the cleared extract is added strong sulphuric acid containing the dye. After the full colour has developed, the boron content is estimated either visually or by the use of a photoelectric colorimeter. The proper colour development depends on the correct acid concentration of the final mixture, which should never vary

much from 93 per cent H_2SO_4 . For this reason the sulphuric acid should be carefully adjusted and scrupulously guarded against moisture contamination both before, during, and after dispensing.

Spectroscopic and spectrographic methods are also employed for boron determinations. As yet, they are somewhat inferior to the colorimetric methods, but the attention being focused on them at the present time should warn one to be on the alert for new procedures. Bertrand and Agulhon (1910) confirmed their tumeric paper test results by the spectrographic examination of colours imparted to a flame of burning hydrogen. It has been found possible to get fairly accurate figures by comparing the spectrum of ashed test-plants with those of a series of controls, providing there is a considerable range in boron content between the controls. By visual comparison, one can arrive at the approximate boron content of plant material.

McHargue, et al (1939), employed a spectroscopic method in which the boron was converted to methyl borate, distilled off, made up to a definite volume with methyl alcohol, and a suitable aliquot taken for determination. The authors compared their method with the colorimetric procedure of Berger and Truog (1944). Very good agreement was obtained between the two procedures with some of the plant materials assayed, while with the remainder, for some reason, agreement was not so satisfactory. In most instances, the colorimetric method gave lower results.

Definite characteristic symptoms appear in a wide range of plants when boron is excluded, but a plant which is sensitive to very minute additions of the element is best suited for a biological test, since, as has already been pointed out, the margin between toxicity and deficiency is very narrow. Schuster and Stephenson (1940) accidentally found that sunflowers of the Mammoth Russian variety clearly demonstrate boron deficiency symptoms when grown in boron deficient soils. Using the sunflower as the indicator plant, Colwell (1943) developed his now widely acclaimed biological method for determining the relative available boron content of soils. Dawson and Gustafson (1945) compared the latter method with that developed by Naftel (1939) for determining hot-water-soluble boron in soils. Within a reasonable error, water-soluble and biologically available boron were found to be identical.

In the Colwell procedure, five sunflower plants are grown in one pound aliquots of soil, and the criterion of the boron status of the soil is the age of the culture when the initial stages of boron deficiency symptoms become apparent. This age is referred to as the "age value". To compensate for variable conditions, a series of quartz sand controls containing known amounts of boron is provided. It is only necessary then to compare the age value of the soil to the age values of the controls in order to estimate the biologically available boron in the soil under investigation.

EXPERIMENTAL

A Study and Comparison of Methods

Available Boron:

Selecting and Checking a Method:

In selecting a method for the determination of water-soluble, or (more appropriately) "available", boron in soils, the writer was at first undecided between the curcumin procedure of Naftel (1939) and the quinalizarin determination of Berger and Truog (1944), both of which employ a hot water extraction. The latter found that, generally speaking, the two methods are of equal accuracy, except that in the case of Naftel's procedure, more care is probably required. McHargue and Hodgkiss (1941) concluded that the quinalizarin method is preferable because of rather wide variations at times with curcumin. One may sum up the merits of each method as follows: in the curcumin procedure, preparation and storage of a strong acid are obviated; difficulties encountered in using strong sulphuric acid, particularly in the photoelectric comparison, are eliminated; and a somewhat wider working range of boron concentration is possible. The advantages of the quinalizarin procedure include: much less manipulation in filtration, washing, and evaporation; hence results are more uniformly accurate.

In view of the above, the quinalizarin procedure as described by Berger and Truog (1944) was employed. The method was followed exactly as outlined by the authors,

except for two minor modifications as suggested by Maunsel (1940): as soon as the concentrated acid had been added to the one ml. aliquot of unknown, the mixture was stirred vigorously with an oven-dried desiccated glass rod, and the vials, instead of being stoppered, were immediately placed in a desiccator containing 98 per cent sulphuric acid. This resulted in more uniform mixing and obviated the necessity of employing stoppers which sometimes contaminated the dye mixture. Owing to the fact that a suitable photoelectric colorimeter was not available, and that the strong sulphuric acid employed in the procedure makes the use of one difficult, visual comparisons were made. In fact, Berger and Truog (1944) maintain that, providing the operator is a good judge of colour shades and intensities, colour comparisons may be made visually with an accuracy equaling or surpassing that possible with a photoelectric colorimeter.

Since boron is of widespread occurrence and a common contaminant of glassware and laboratory reagents, blanks were frequently carried out on all apparatus and chemicals and the data corrected accordingly. In addition, known amounts of boric acid were added to water in the reflux flasks, and, in most cases, all of it was recovered. Further, in order to check the writer's technique thoroughly, soils of known available boron content were obtained from Professor Truog, of the University of Wisconsin. These were analyzed accordingly and the data, which show a close measure of

agreement between Truog's and the writer's analyses, are shown in Table II.

TABLE II.-

Analyses of Soil Samples Obtained from
Professor Truog, University of Wisconsin, for
Available Boron

Soil Type	p.p.m. Available Boron	
	Truog	Fennell
Cropped Miami Silt Loam.....	0.15	0.13
Cropped Miami Silt Loam.....	0.50	0.50
Virgin Carrington Silt Loam.....	1.05	1.10
Virgin Miami Silt Loam.....	1.60	1.63

**A Comparison of Biologically and Chemically
Available Boron:**

One of the main problems confronting the analyst when determining available boron in soils is the choice of an extracting solution which will duplicate the extracting power of the plant. Among those which have been tried are dilute hydrochloric acid, dilute sulphuric acid, carbonic acid, and hot and cold water. De Turk and Olsen (1941) indicate that water-soluble boron is a fairly reliable measure of the available boron content of soils, but the

work of Woodbridge (1940) demonstrated that single extractions with cold water, or water saturated with carbon dioxide, removed only a small portion of it. Berger and Truog (1944) found, too, that even hot water shaken up with soil would not extract all of the boron previously added as boric acid. They further demonstrated that, although dilute hydrochloric acid extracts most of the readily soluble boron, tests made in this manner on calcareous soils do not correlate well with crop indications of the boron status. After numerous tests, the authors found that refluxing soil water mixtures for five minutes gave results that correlated well with plant response to boron fertilization, and it is this method of extraction that is employed in the quinalizarin procedure used in the present instance. In order to be reassured, at the outset of the study, that this correlation held for British Columbia conditions, surface soils and parent materials of soil types from the Fraser Valley, Central Interior, and Peace River Block, previously analyzed by the Berger and Truog (1944) method, were also tested by the biological analysis of Colwell (1943).

In order to calculate the available boron content of the above mentioned soils by the latter method, a series of quartz sand controls, containing known amounts of added boron, was set up and carried for 48 days. This was done along with the series of soils, and, like the latter, was not carried beyond the 48-day period, due to the development of

adverse greenhouse conditions.

TABLE III.-

^x
The Quartz Sand Controls Used for the
Estimation of Biologically Available Boron
in the Soils Listed in Table IV.

p.p.m. Boron Added	Age Value† in Days
0.00	13
0.05	18
0.10	22
0.30	27
0.50	32
1.00	44

^x1 lb. aliquots of quartz sand.

†Average age of 5 plants when boron deficiency symptoms first appeared.

The data concerning these quartz controls are presented in Table III, and it is to be observed that a 22-day age value, for instance, corresponds to 0.1 p.p.m. of boron.

Figure 1 is presented to demonstrate a typical series of quartz sand controls from another experiment, the data for which differ slightly from those shown in Table III. This, of course, is due to the fact that greenhouse conditions vary from time to time, and stresses the necessity of providing a set of controls for each experiment.

The Colwell, or biological method, was followed exactly as described by the authors, except that, in the case of

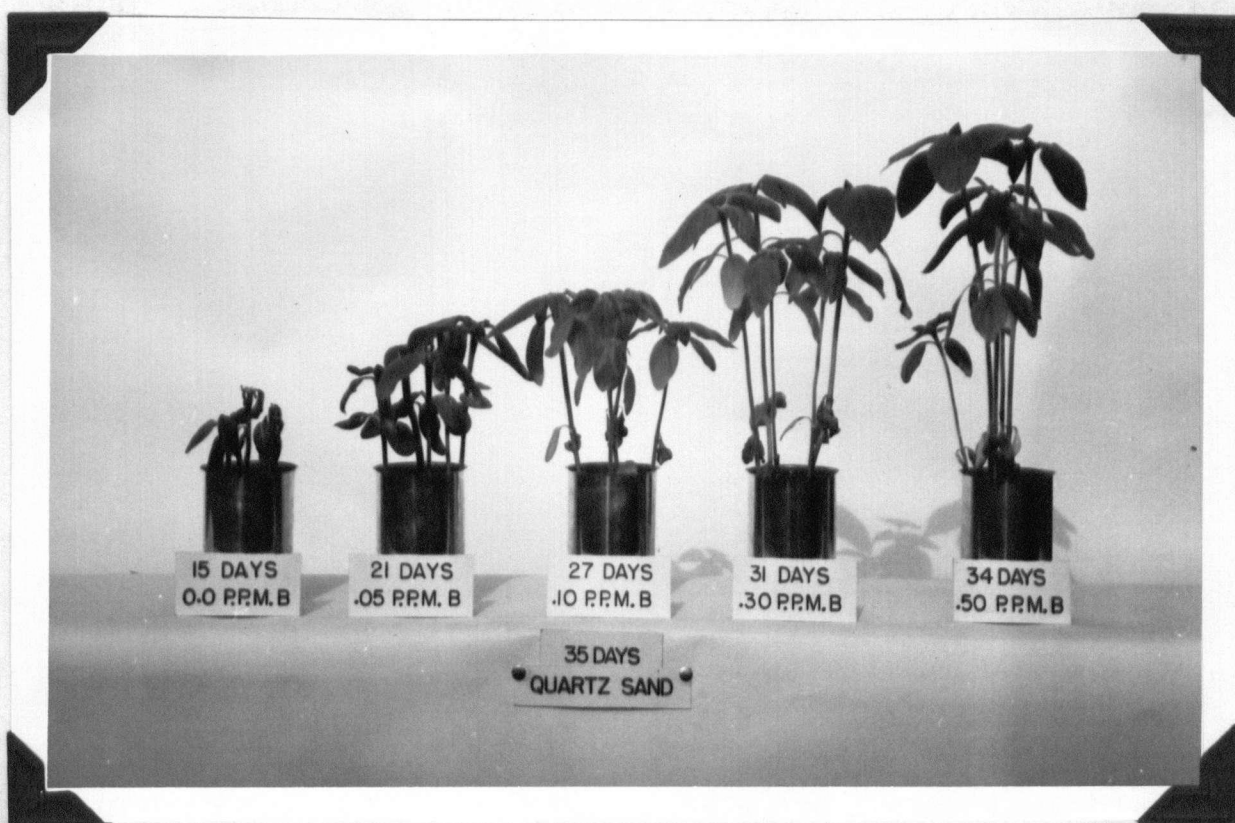


Fig. 1

Quartz sand controls consisting of five sunflower plants growing in one pound aliquots of quartz sand to which increasing amounts of boron as boric acid have been added. The number of days listed on the card along with the concentration of boron refers to the age of the plant when boron deficiency symptoms first appeared, and is termed the "age value". All cultures are 35 days old.

soils with a low volume weight, one-half or three-quarter pound aliquots were used in place of the standard one-pound samples. In such cases, after the boron content had been estimated by comparing the age value with the controls, it was multiplied by 2 or $\frac{4}{3}$ as required. This gave the boron content of the soil in parts per million on the basis of a one-pound aliquot.

The data comparing the two methods using British Columbia soils are presented in Table IV. Available boron by the biological method is calculated from the age values as presented in Table III. For instance, a study of Table IV reveals that Lakelse clay (No. 19) has an age value of 27 days. Comparing this to the quartz sand controls of Table III, one observes that plants growing in quartz sand containing 0.30 p.p.m. boron also developed deficiency symptoms at 27 days. Therefore, it is assumed that No. 19 has an available boron content of 0.3 p.p.m. Again, Ladner clay (No. 204) has an age value of 32 days. The controls show that this figure represents 0.50 p.p.m. But since only 0.5 lb. of soil was used, the result is multiplied by 2, giving an available boron content of 1.0 p.p.m. The boron content of soils, whose age values come in between those of the quartz sand controls, is estimated as closely as possible.

An examination of the data as presented in Table IV reveals a very close correlation between the two methods. At the same time, it should be pointed out that, with the clays and clay loams, the biological analyses appear to be

TABLE IV.-
A Comparison of the Biological and Chemical Analyses
for Determining Available Boron in Soils
Date of Planting July 7, 1947^{*}

Sample No.	Soil Type	Depth	Weight Soil lbs.	Age Value ^x Days	Available Boron p.p.m.	
					Biol.	Chem.
13	Hazelon Sandy Loam.....	A	1.00	25	0.30	0.30
14	Hazelon Sandy Loam.....	C	1.00	24	0.20	0.25
18	Lakelse Clay....	1/2"-7"	0.75	27	0.40	0.45
19	Lakelse Clay....	31"	1.00	27	0.30	0.20
11	Pineview Clay...	A ₂	0.75	--	--	1.25
12	Pineview Clay...	C	1.00	40	0.80	0.60
15	Bednesti Silt Loam.....	A	1.00	--	--	1.50
16	Bednesti Silt Loam.....	C	1.00	--	--	2.00
1	Ft.St.James Clay	A	0.75	44	1.32	1.23
2	Ft.St.James Clay	C	1.00	44	1.00	0.75
48	Waterhole Clay Loam.....	0-8"	1.00	--	--	2.05
54	Nampa Clay.....	0-8"	1.00	--	--	1.45
50	Rycroft Clay....	0-8"	1.00	--	--	2.80
52	Peace River Clay	0-8"	1.00	--	--	1.45
28	Monroe Clay.....	0-6"	0.50	33	1.00	0.80
30	Monroe Clay Loam	0-8"	1.00	34	0.60	0.60
47	Monroe Loamy Sand	0-6"	1.00	16	0.03	0.05
204	Ladner Clay.....	0-6"	0.50	32	1.00	--
27	Haney Clay.....	0-8"	0.75	31	0.65	0.65
34	Milner Clay Loam	0-6"	0.50	29	0.70	0.65
35	Milner Clay Loam	15-20"	0.75	33	0.75	0.65
32	Langley Clay Lm.	0-8"	0.75	34	0.80	0.75
39	Custer Loam.....	0-5"	0.50	30	0.90	0.85
43	Everett Grav. Sandy Loam....	0-6"	1.00	30	0.45	0.40
45	Everett Loamy Sand.....	0-6"	1.00	30	0.45	0.45
41	Alderwood Silt Loam.....	0-6"	0.75	26	0.40	0.50
38	Lynden Silt Loam	0-6"	0.75	32	0.67	0.60
36	Whatcom Silt Loam.....	0-6"	0.75	32	0.67	0.70

^{*}Experiment terminated 48 days after planting.

^xAverage "Age Value" for 5 sunflower plants.

slightly higher on the average than the chemical assays. This is precisely what one might expect for Whatstone, et al (1942) have demonstrated that most of the potentially available boron in soils is found in the colloids, while Eaton, et al (1941), have shown that recovery of boron by leaching from clay soils is usually more difficult than from coarse-textured soils. Soils, such as Pineview, Munroe and Fort St. James clay, which gave a somewhat higher analysis by the biological method, are undoubtedly high in colloids. Thus, boron which would not necessarily show up in the chemical test, might still be available to the plant. Such behaviour would seem to be a point in favour of the biological method. Bearing these points in mind, this preliminary study indicates an excellent measure of agreement between the two methods, and one is therefore justified in concluding that, when the hot-water-soluble quinalizarin method shows a soil to be low in available boron, it is low in biologically available boron.

In Figure 2, one may compare the appearance of plants growing in soils and parent materials deficient in available boron, with that of plants growing in a soil containing a sufficiency of the element.

Total Boron:

Since much of the soil boron may exist as extremely resistant tourmaline, it is necessary to employ a fusion to render all of the boron soluble. Once this is done, the



Fig. 2

Boron deficient and healthy sunflower plants growing in soils and parent materials listed below. Data concerning these cultures are presented in Table IV. All cultures are 44 days old.

<u>Culture No.</u>	<u>Soil</u>
1.	Munroe loamy sand (No. 47);
2.	Hazelton sandy loam (No. 13);
3.	Hazelton sandy loam (No. 14);
4.	Lakelse clay (No. 18);
5.	Lakelse clay (No. 19);
6.	Ft. St. James clay (No. 1).

boron can be determined by one of the usual methods. Whetstone, et al (1942), employ a sodium acid phosphate fusion followed by a distillation and electrometric titration, while Berger and Truog (1944) use a sodium carbonate fusion followed by the usual quinalizarin colorimetric determination. McHargue and Hodgkiss (1941) report that the latter method appears to be the more satisfactory of the two, and, on the strength of this, it was adopted in the present study. The procedure was followed exactly as described. In order to once again guard against error, the procedure and technique were checked against known amounts of sodium tetra borate added to 3 grams of sodium carbonate. The results of the analyses are shown in Table V and are well within the range of experimental error.

TABLE V.-

Recovery of Boron Added as Sodium Tetraborate
($\text{Na}_2\text{B}_4\text{O}_7 \cdot 10 \text{H}_2\text{O}$) by Total Analysis Method

Mgms. Boron Added	Mgms. Boron Recovered	Average Mgms.
.002	.0021, .0018, .0022, .0017, .0020	.0019

It might be well to stress the fact that, in this procedure, as with the other, controls were run frequently and the necessary adjustments made. The controls always seemed to give fairly high results, which was probably due to the comparatively large quantities of reagents used in the method for the determination of total boron.

Nomenclature:

Because of the several methods for extracting boron from soils, there is often doubt concerning the form of the element actually referred to. Before proceeding further, it might be well to define clearly and concisely the three forms of boron that will be mentioned frequently during the ensuing discussions:

- (1) Available boron:- That fraction extracted after refluxing a 1:2 soil water mixture for five minutes;
- (2) Reserve or maximum available, also known as acid-soluble boron:- That portion made soluble after digesting the soil with 85 per cent phosphoric acid on a hot water bath. (N.B. This fraction was not determined in British Columbia soils, but will be referred to frequently);
- (3) Total boron:- The boron determined following a soil fusion. This includes all the boron in the soil.

Relation of Boron Content of Soils to
Major Soil Groups and Parent Material

Whetstone, et al (1942), have shown that the boron status of American soils is closely related to the great soil groups and to parent material. This data demonstrates that soils derived from alluvion, limestone, shale and glacial drift are high in acid-soluble boron which they assumed to represent the reserve or maximum available boron. In addition, Podzola, Half Bog, muck, and Red and Yellow

Podzolic soils were found to be low, while alluvial, Gray-Brown Podzolic, Prairie, Chestnut, Brown and Chernozem soils were high in acid-soluble boron. The low content of reserve boron in soils of the Pacific Northwest, which is assumed to include the Okanagan area, was concluded to be due to the inherently low boron content of the parent material.

For the purpose in mind, in the present instance, it was decided to determine total and available boron rather than acid-soluble, and attempt to relate same to soils and parent materials of the major soil groups of British Columbia. Accordingly, samples representing the Degraded Black, Gray Wooded and Pacific Coast zone were selected.

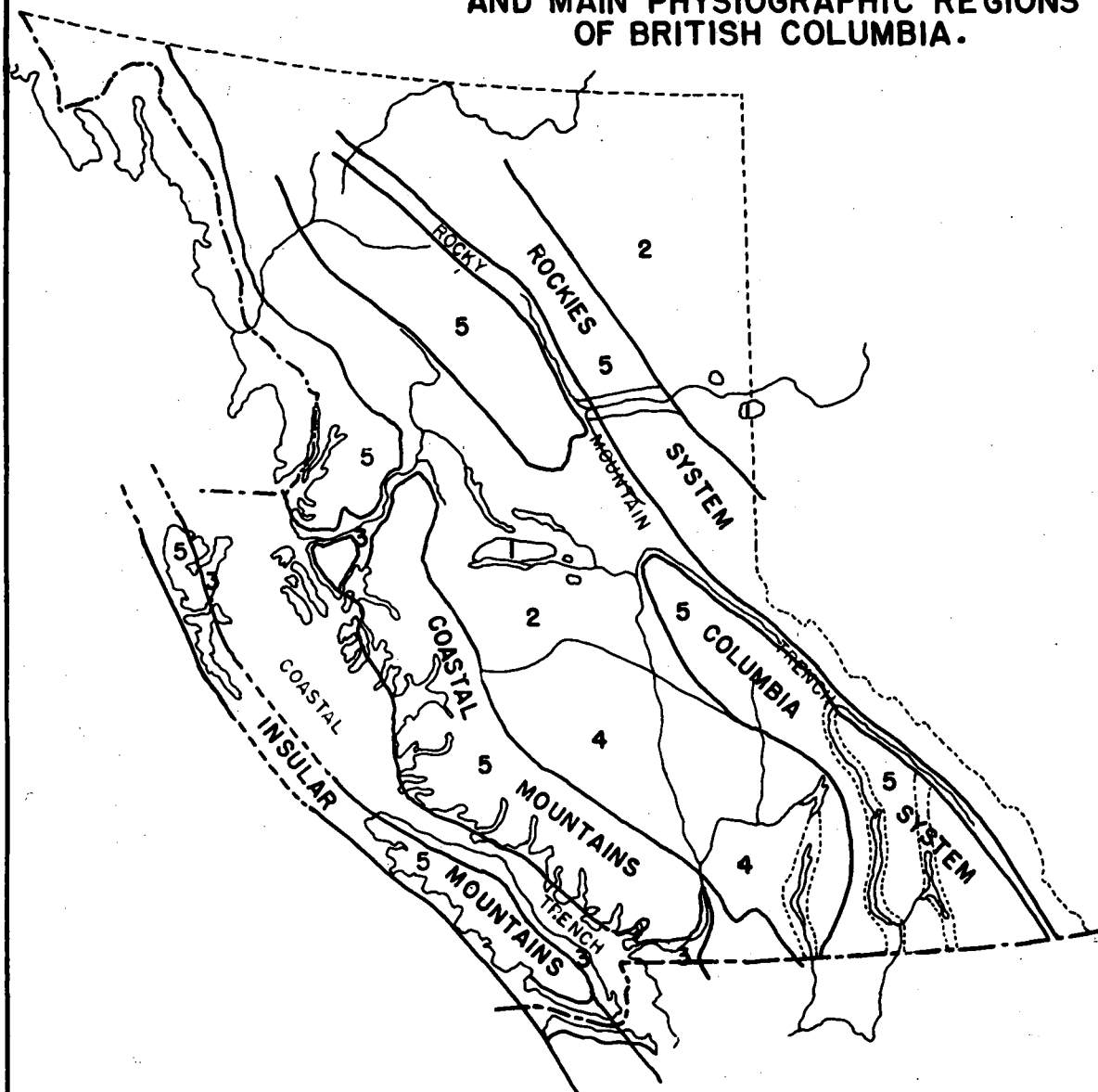
The data concerning analyses of a few samples from another soil zone--the Interior Plateau--are also included, not so much for the purpose of presenting a picture, but rather to tie in with the work of Woodbridge (1940) and to ascertain the difference in available boron resulting from applications of same.

The various zones are shown in Chart II.

The influence of pH and organic matter on the supply of available boron has, too, received some attention, and data concerning this is presented along with data for total and available boron in the following tables. For the determination of organic matter, the method of Walkley and Black (1934) was used, while for pH determinations, a glass electrode and a 1:1 suspension of soil and water which had been allowed to

CHART II.

APPROXIMATE DISTRIBUTION
OF THE MAJOR SOIL ZONES
AND MAIN PHYSIOGRAPHIC REGIONS
OF BRITISH COLUMBIA.



- | | |
|---|---|
| 1 | SOILS OF THE DEGRADED BLACK ZONE |
| 2 | SOILS OF THE GRAY WOODED ZONE |
| 3 | SOILS OF THE PACIFIC COAST ZONE |
| 4 | SOILS OF THE INTERIOR PLATEAU (ZONAL COMPLEX) |
| 5 | UNDIFFERENTIATED MOUNTAINOUS LANDS |

stand for 30 minutes, were employed. To avoid the introduction of too many factors, the discussion of organic matter and pH will be reserved largely for a later section.

Degraded Black Zone:

Soils of the Degraded Black zone comprise two relatively small areas in the Peace River Block and three in the Central Interior of British Columbia, one of which is quite large. For specific location of these areas, see the map in Chart II.

The data concerning the soils of this zone are presented in Table VI. The soils of the Peace River subjected to study were of lacustrine and glacial till origin.

Both parent materials and cultivated soils derived therefrom show approximately the same total boron content (62.5 to 75.0 p.p.m.). This would appear to suggest that the parent materials are of the same origin. The suggestion is further supported through the fact that the till is largely clay and of the same general character as the lacustrine clay. In view of the fact that Whetstone, et al (1942), found the total boron of American soils to average 30 p.p.m., the total values for the Peace River soils are high. It is interesting to observe, too, that this high total boron content on these Degraded Black soils is in conformity with the observations of the last mentioned in respect to acid-soluble boron in Prairie and Chernozem

**TABLE VI.- Boron Content and Related Data Pertaining to Soils
of the Degraded Black Zone**

Sample No.	Identity of Soil	Origin	Remarks	Depth	P.P.m. Boron		% O.M.	pH
					Available	Total		
PEACE RIVER BLOCK								
48	Waterhole c.l.	Glacial till	Cult.	0-6"	2.05	62.5		
49	" "	" "	Parent Mat.	6'	1.40	75.0		
50	Rycroft c.	Lacustrine	Cult.	0.8"	2.80	75.0		
51	" "	"	Parent Mat.	6'	0.60	70.0		
CENTRAL INTERIOR								
1	Fort St.James c.	Lacustrine	Virgin	0-6"	1.23	23.0		
2	" " " "	"	Parent Mat.	36"	0.75	21.5		
3	Driftwood l.	Glacial till	Virgin	0-6"	2.00	21.5		
4	" " " "	" "	Parent Mat.	30"	0.70	29.0		
67	" " " "	" "	Cult.	0-6"	1.70		11.45	6.1
68	" " " "	" "	"	0-6"	0.50		15.93	5.6
72	" " " "	" "	"	0-6"	1.00		7.53	7.0
73	" " " "	" "	"	0-6"	0.80		9.42	7.2
74	" " " "	" "	"	0-6"	0.90		5.93	6.9
5	Telkwa c.	Shallow lacustrine	"	0-6"	0.85	26.5		
6	" " " "	" "	Parent Mat.	12-15"	0.50	31.5		
7	Nulki c.	Lacustrine	Cult.	0-6"	1.50	5.0		
8	" " " "	"	Parent Mat.	30"	0.45	10.0		

c. - clay, c.l. - clay loam, l. - loam.

N.B.- The figures for the boron analyses in the above, and all other tables, were obtained by averaging duplicate determinations.

soils, since clays with a high total content are almost certain to have a high reserve.

The Central Interior Degraded Black soils have an average total boron content very much lower than that for the Peace River soils. Here again, the fact that the soil was derived from glacial till or lacustrine material seems to have little or no bearing on the total boron content. The significant fact seems to be that the Central Interior soils are formed from materials much lower in total boron than the parent material for the Peace River soils. This is a very interesting observation in view of the fact that some authorities are inclined to believe that the Peace River soils have been derived from Keewatin glacial material, while those of the Central Interior have come from the west.

Woodbridge (1937) showed that Okanagan soils should contain at least 0.5 p.p.m. of cold-water-soluble boron for apple trees to be free from boron deficiency troubles. Dregne and Powers (1942) concluded that, for the healthy growth of alfalfa, 1.0 p.p.m. of available boron was necessary in the soil. In the writer's investigation, no data has been recorded on the available boron content of virgin Peace River soils, but, in view of the above reference to crop requirements, the content of cultivated soils in this area remains high. One might infer that these soils have a high boron reserve in the clay colloids. Such a condition would fortify the soil against cropping and leaching losses. On the other

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hand, the Driftwood loam in the Central Interior shows that the available boron content drops from 2.0 p.p.m. in a virgin sample to an average of 0.98 p.p.m. in cultivated soils. Since precipitation in the two areas is approximately the same, further work will be necessary in order to explain the observation. However, it is suggested that the difference in soil texture combined with the typically coarse, stony formation of a glacial till parent material probably low in reserve boron, offer an explanation.

The soils of the Degraded Black zone were at one time, if not now, covered by a grassland vegetation, which in turn means limited precipitation with relatively little leaching. Succeeding generations of grasses, with their fibrous root systems, brought boron to the surface and accumulated some of the A₀ and A₁ horizons. Thus one would expect a higher concentration of available boron in the surface soils than in the parent material. This is adequately borne out in the data submitted in Table VI. For instance, the average for available boron in surface soils of the Degraded Blacks is 1.74 p.p.m., while in the parent material it is 0.73 p.p.m.

From the foregoing review, one may conclude that virgin soils in the Degraded Black zone are well supplied with available boron. However, following cultivation, it is apparent that Central Interior soils of this zone may, after a time, become depleted, whereas the Peace River soils, due to the inherently high boron content of the parent material, appear to have a high reserve. As yet no boron deficiency

symptoms have been reported in any of the crops grown in Degraded Black soils.

Gray Wooded Zone:

With the exception of the small Degraded Black areas already referred to, the Gray Wooded soils occupy practically all of the agricultural areas in the Peace River Block and Central Interior. Three other much less extensive areas where the Gray Wooded soils occur are the Arrow Lake, Kootenay Lake, and Rocky Mountain trenches. The latter have not been dealt with in this study. Reference to the map shown in Chart II will give exact location of this zone.

The data concerning the Gray Wooded soils are presented in Table VII. Those from the Peace River area are high in total boron, averaging 60 p.p.m. As with the soils from the Degraded Black zone, the origin of the parent material seems to have little effect on the total boron content.

Like the Degraded Black, the Gray Wooded soils from the Central Interior have a much lower total boron content than do those from the Peace River Block. This again suggests the theory that the parent material of Central Interior soils differs widely from the parent material for the Peace River area.

Apart from these regional differences in parent material, the post-glacial Fraser silt loam and Hazelton sandy loam, which are quite loose unretentive soils, have very low available boron content. This supports the findings of several workers who all seem to agree that soils formed from

TABLE VII.-
Boron Content of, and Related Data Pertaining to, Soils
of the Gray Wooded Zone

Sample No.	Identify of Soil	Origin	Remarks	Depth	P.p.m. Boron		O.M.	pH
					Avail-able	Total		
PEACE RIVER BLOCK								
52	Clay	Lacustrine	Cult.	0-8"	1.45	72.0		
53	"	"	Parent Mat.	5'	1.30	52.5		
54	Nampa c.	Glacial till	Cult.	0-8"	1.45	50.0		
55	" "	" "	Parent Mat.	100'	0.50	65.0		
56	" "	" "	" "	6'	1.55	65.0		
CENTRAL INTERIOR								
9	Vanderhoof c.	Lacustrine	Virgin	2-6"	0.95	19.0		
10	" "	"	"	30"	1.75	27.0		
57	" "	"	Cult.	0-8"	0.20		5.41	7.2
58	" "	"	Cult.	0-6"	1.10		4.42	6.7
59	" "	"	Parent Mat.	30"	0.72		.44	7.6
60	" "	"	Cult.	0-6"	0.60		4.11	6.8
61	" "	"	Cult.	0-6"	0.45		10.52	6.8
62	" "	"	Sub-soil		0.10		6.40	6.6
11	Pineview c.	"	Virgin	2-7"	1.25	12.0		
12	" "	"	"	36"	0.60	4.0		
64	" "	"	Cult.	0-6"	0.40		5.08	5.1
65	" "	"	Parent Mat.	27"	0.30		.41	6.2
15	Bednesti si.l.		Virgin	2-6"	1.50	29.0		
16	" "		Parent Mat.	28"	2.00	31.5		
66	Fraser si.l.	Alluvial	Cult.	0-6"	0.20		1.24	6.6
13	Hazelton s.l.	"	Cult.	0-6"	0.30	12.0		
14	" "	"	Parent Mat.	24"	0.25	9.0		
63	" "	"	Cult.	0-6"	0.20		3.00	6.2

c. - clay, s.l. - silt loam, s.l. - sandy loam

unconsolidated, or coarse, material is generally low in available boron.

The cultivated Peace River soils and the virgin Central Interior soils are well supplied in the above respect. Following cultivation, however, the last named suffer a sharp decline in available boron, while the level of the Peace River soils remains high. For instance, virgin Pineview clay (No. 11) has an available boron content of 1.25 p.p.m., while No. 64, a cultivated surface sample, only contains 0.40 p.p.m. Again, in the case of virgin Vanderhoof clay (No. 9), the available boron content is 0.95 p.p.m., while the average for cultivated samples (Nos. 57, 58, 60, 61) is only 0.6 p.p.m.

In reference to the available boron in surface soils and parent materials of the Gray Wooded zone as a whole, the averages are 1.05 and 1.00 p.p.m., respectively. This indicates that the influence of a forest vegetation promotes more extensive leaching and much of the boron is washed down to lower levels where it is retained in the colloids. Hazelton sandy loam (Nos. 13, 14) does not demonstrate this difference due to its inherently low available boron content and the unretentive nature of its sub-soil.

Relation of Experimental Data to Practice:

As yet, no boron deficiencies have been reported in the Gray Wooded zone of the Peace River Block. In the Central Interior, however, as one may conclude from the foregoing data, the use of boron fertilizers to improve crop

yields and quality in this soil zone is not uncommon. Such fertilizers have been used for some time at the Prince George Experiment Station, while the District Agriculturist from Smithers has found indications of boron deficiencies in the following localities:

Woodcock - Swede turnips.
Kispiox Valley - Apple trees and swede turnips.
Bulkley Valley - Alfalfa and swede turnips.
Ft. Fraser and Vanderhoof - Alfalfa.

The deficiency does not appear to be generally prevalent in these areas, but has been noted locally in the above districts. Alfalfa and swede turnips appear to be the crops which benefit the most from boron applications. When used, boron has been applied as sodium tetraborate, or borax, at 10 to 15 pounds per acre for alfalfa and 20 to 30 pounds for swede turnips.

The soils of the Quesnel district, which partly lie within the Gray Wooded zone, are reported by the District Agriculturist of that area to be generally lacking in boron. The deficiency is indicated especially in swede turnips, alfalfa, and potatoes. Borax is applied at the rate of 15 to 30 pounds to the acre.

Pacific Coast Zone:

The soils of this zone, as the name implies, are found along the West Coast of British Columbia. As one may expect, they extend into the United States. This is significant in that much of the data concerning the boron status of Western Washington soils is probably, in many instances, applicable

to the soils of British Columbia. For the exact location of the soils of this zone, see the map in Chart II:

The data concerning the Pacific Coast zone soils are presented in Table VIII, and, for the sake of simplifying the discussion, are grouped according to the geographical area from which they were secured.

Terrace District:

It will be observed in Table VIII that, for the Terrace District, relatively few samples were examined, but the data, nevertheless, are probably indicative of prevailing boron content. A wide range in total boron is suggested with an average (3 samples) of 31.5 p.p.m., which is slightly higher than that for the Central Interior and approximately the same as that reported for American soils.

The surface soils, aside from No. 78, give an average available boron content of 0.44 p.p.m., which is decidedly low. The surface sample omitted from the average appears for some reason to be out of line with the others. The light-textured soils, Terrace and Skeena sandy loams, appear to have lower available contents than the Lakelse clay, which is in line with expectation, owing to the higher colloidal content of the latter. The parent material, as is to be expected, has a distinctly low available boron content.

Vancouver Island:

Of the Vancouver Island samples investigated, only two were analyzed for total boron. These were parent materials

TABLE VIII.-
Boron Content and Related Data Pertaining to Soils
of the Pacific Coast Zone

Sample No.	Identity of Soil	Origin	Remarks	Depth	p.p.m. Boron		O.M.	pH
					Avail.	Total		
<u>TERRACE DISTRICT</u>								
18	Lakelse c.	Lacustrine	Virgin	1-7"	0.45	26.5		
19	" "	"	Parent mat.	31"	0.15	44.0		
77	" "	"	Cult.	0-6"	0.40		3.37	5.8
78	" "	"	"	0-6"	1.50		3.53	6.0
17	Terrace s.l.	Alluvial	"	0-6"	0.60	24.0		
76	" "	"	"	0-6"	0.20		2.88	5.8
75	Skeena s.l.	"	"	0-6"	0.22		7.89	5.1
<u>VANCOUVER ISLAND</u>								
79	Cowichan c.	Lacustrine	Cleared - sod	0-8"	0.15		7.4	5.1
84	" "	"	Second growth - past.	0-6"	0.20		7.21	
20	Cowichan c.l.	"	Virgin	0-1"	0.20		5.58	5.40
21	" "	"	Parent mat.	6'	0.10	35.0	0.52	6.50
88	Bainbridge c.l.	Glacial till	Virgin	0-6"	0.30		11.40	5.60
86	Bainbridge l.	" "	Second growth	0-6"	0.10		10.00	5.70
22	Bainbridge s.l.	" "	Virgin	A2	0.50		9.61	4.0
23	" "	" "	Parent mat.	6'	0.00	32.5	.69	5.8
82	Qualicum l.s.	Alluvial	Logged	0-6"	0.05		3.12	5.8
81	Delta	"	Past.	0-6"	0.60		4.25	5.8
90	Cowichan c.l.	Lacustrine		0-6"	0.10		4.13	5.4

Continued.....

TABLE VIII (Continued)

Sample No.	Identity of Soil	Origin	Remarks	Depth	p.p.m. Boron		O.M.	pH
					Avail.	Total		
<u>LOWER FRASER VALLEY</u>								
25	Peat		McLennan Sta. virgin	0-6"	7.00	17.00	--	---
36	"		Langley - past.	"	5.00	--	--	5.05
37	"		" "	"	2.50	--	--	4.75
158	"		?	"	1.50	--	--	4.70
163	"		?	"	1.90	--	--	4.20
164	"		?	"	2.50	--	--	5.50
165	"		Cloverdale		16.00			4.70
167	"		Chilliwack		5.60			4.30
101	Ladner c.	Recent alluvial	Pitt River - past.	"	1.00	--	14.80	4.60
102	"		Hammond - cult.	"	1.50	--	14.70	4.10
103	"		Matsqui - past.	"	0.40	--	--	5.95
104	"		Sea Isl. - past.	"	0.70	--	3.40	5.50
162	"		" " "	"	2.30	--	5.10	7.30
105	"		Lulu Isl. - past.	"	1.50	--	5.85	5.15
220	"		" " - cult.	"	2.00	--	--	4.10
160	"		Ladner - cult.	"	5.00	--	8.81	6.00
28	Munroe c.		Virgin	"	0.80	12.0	--	--
29	"		Parent mat.	12-18"	0.50	15.0	--	--
30	Munroe c.l.		Virgin	0-8"	0.60	17.5	--	--
31	"		Parent mat.	14-20"	0.70	10.0	--	--
108	"		Past.	0-6"	0.65	--	6.97	5.70
47	Munroe l.s.		Virgin	"	0.05	5.0	--	--
122	"		Nut orchard	"	0.45	--	1.38	6.10
123	"		Abandoned past.	"	0.30	--	0.83	5.80
124	"		Abandoned	"	0.05	--	0.72	6.20

Continued.....

TABLE VIII (Continued)

Sample No.	Identity of Soil	Origin	Remarks	Depth	p.p.m. Boron		O.M.	pH
					Avail.	Total		
32	Langley c.l.	Ground	Virgin	0-8"	0.70	20.0	--	--
33	"	Water	Parent mat.	15-20"	0.85	17.5	--	--
39	Custer l.	Soils Glac	Virgin	0-5"	0.70	10.0	--	--
40	"		Parent mat.	12-18"	0.60	10.0	--	--
26	Haney c.	Past. Glac Delta Drainage fair	Virgin	0-8"	0.65	15.00	--	--
27	"		Parent mat.	20-25"	0.50	18.50	--	--
107	"		Red clover	0-6"	0.55	--	10.20	5.40
34	Milner c.l.		Virgin	0-6"	0.65	15.00	--	--
35	"		Parent mat.	15-20"	0.65	17.50	--	--
109	"		Perm. past.	0-6"	0.70	--	9.40	5.30
110	"		Abandoned past.	0-6"	0.65	--	9.55	5.10
36	Whatcom si.l	Upland glacial. Restricted sub-drain- age.	Virgin	0-6"	0.70	22.5	--	--
37	"		Parent mat.	24"	0.60	20.0	--	--
115	"		Virgin	0-6"	0.60	--	10.20	5.40
116	"		Past.	0-6"	0.50	--	1.39	5.75
41	Alderwood si.l.		Virgin	0-6"	0.50	10.0	--	--
112	"		"	0-6"	0.80	--	6.75	5.30
113	"		?	0-6"	0.45	--	--	5.35
114	"		Past.	0-6"	0.60	--	11.20	5.50
42	Alderwood s.l.		Virgin	6-12"	0.60	20.0	--	--
118	"		"	0-6"	0.30	--	6.17	5.60
38	Lynden si.l	Upland modified glacial drift. Drainage excessive	Virgin	0-6"	0.60	18.0	--	--
111	"		Past.	0-6"	0.40	--	9.05	5.60
43	Everett g.s.l.		Virgin	0-6"	0.40	15.0	--	--
44	"		Parent mat.	20-24"	0.20	18.0	--	--
119	"		Past.	0-6"	0.60	--	7.10	5.40
120	"		Virgin	0-6"	0.50	--	6.10	5.40
121	"		Hayfield	0-6"	0.70	--	11.80	5.20
45	Everett l.s.		Virgin	0-6"	0.45	10.0	--	--
46	"		Parent mat.	15"	0.20	10.0	--	--

c. - clay, c.l. - clay loam, si.l. - silt loam, l. - loam, s.l. - sandy loam,
g.s.l. - gravelly sandy loam, l.s. - loamy sand

(Nos. 21 and 23), and indicate approximately the same content with a mean of 33.8 p.p.m. This appears to be about the same as for the corresponding textural groups in the Terrace District.

The available boron content of virgin and cultivated soils indicates a range of 0.05 to 0.6 p.p.m. with a mean of 0.24 p.p.m., which is distinctly low. In fact, it suggests a surprisingly low available boron content when one observes that the organic matter content for the same soils averages very close to 7 per cent. Very likely the heavy precipitation is the controlling factor. It is concluded from the data presented that Vancouver Island soils are, in general, deficient in available boron.

The Lower Fraser Valley:

Reference to Table VIII discloses that only one sample of peat from the Lower Fraser Valley was analyzed for total boron and found to contain 17.0 p.p.m., of which 7.0 p.p.m. were available. This sample represented a virgin peat. Six other samples taken from pasture lands indicate a range from 1.5 to 5.6 p.p.m. of available boron with an average of 3.1, while one well decomposed peat from Cloverdale gave a figure of 16.0 p.p.m. A wide variation is therefore apparent, but in every case there appears to be an abundance, and what appears to be an excess in some cases; yet, so far as the writer is aware, no evidence of boron toxicity has ever been encountered. In spite of the high minimum observed, Harris

(1943) has reported response to a boron application on a well-limed peat.

Considering the usually low pH of Fraser Valley peats and the high annual rainfall of the area, it is more than likely that peats lose their boron very rapidly as boric acid. This might account for the wide variation in the available boron content of the samples discussed. Whetstone, et al (1942), have reported that peats are generally low in reserve boron. If such is the case for the Fraser Valley peats, once their available supply is exhausted there would be no reserve to drawn from.

No data were secured on the total boron content of Ladner clay, but the figures for available boron are of considerable interest. The variation is quite marked, as six samples show a range of 0.7 to 2.3 with a mean of 1.5 p.p.m. At the same time, one sample from Matsqui showed a drop to 0.4 p.p.m., while another from Ladner gave a high value of 5.0 p.p.m. It is evident from these data that Ladner clay is adequately supplied with available boron, with the possible exception of that in the vicinity of Matsqui. A study of the data and specific location of the samples used leads one to suggest that the higher levels of available boron in Ladner clay are in close proximity to peat deposits or correlated with seepage of sea water. Moberg, et al (1933), have reported that the average boron content of sea water is 4.5 p.p.m. Lehr (1940) is responsible for the statement that peat

and marine clay soils of Holland contain sufficient boron for plant growth. Krugel, et al (1941), demonstrated that soils in the neighborhood of Hamburg, which had received a covering of marine silt, had a water-soluble boron content of 14 p.p.m. It seems reasonable to suppose that the available boron content of soils near the mouth of the Fraser River may be augmented by sea water.

Twenty-three determinations for total boron, covering all the major mineral soils with the exception of Ladner clay, disclose the low average content of 14.8 p.p.m. This is distinctly below the figures for the other soil zones already discussed. The lows are observed in Munroe loamy sand with 5 p.p.m., and Everett loamy sand, Alderwood silt loam, and Custer loam with 10 p.p.m., while a high of 22 p.p.m. occurs in the Whatcom silt loam. There is very little difference between total boron of parent material and virgin soils.

The excessively drained soil members (Lynden silt loam, Everett gravelly sandy loam, and Everett loamy sand--particularly the last named) are distinctly low in available boron. This is also the case with the recent alluvial or Munroe loamy sand. The Alderwood sandy loam, with slightly restricted sub-drainage, is, too, quite low. The remainder of these soils shows relatively little difference, with a higher average content lying between 0.6 and 0.8 p.p.m. One is therefore safe in concluding that the loamy sands are low in available boron and that leaching, or excessive drainage, is

an important factor in this respect.

It is well here to draw attention again to the fact that Dregne and Powers (1942) conclude that an alfalfa soil should contain 1.0 p.p.m. available boron, while according to Woodbridge (1937) apple trees require a minimum of 0.5 p.p.m. cold-water-soluble boron. Using these figures as a rough guide, many of the Fraser Valley soils may require boron applications where alfalfa, or perhaps root crops, are being grown. For crops with low boron requirements, there is probably enough of the element present, except in the instances recently mentioned.

Relation of Experimental Data to Practice:

The foregoing data, indicative of boron deficiencies in many soils of the Pacific Coast zone, are at least verified by some field data.

Boron deficiencies in Terrace have been noted in apple orchards by the District Agriculturist from Smithers, B.C.

Observation and experimental evidence indicate that Vancouver Island soils are, generally speaking, low in available boron. Boron deficiencies have been suspected at Alberni. Confirmatory evidence in this respect is provided in a Dominion Illustration Station report (1945). In a plot test, sodium tetraborate, applied at the rate of 20 pounds per acre, increased the percentage of turnips free from boron deficiency symptoms from 6 to 95 per cent. The District

Agriculturist from Courtenay reports that turnips grown on Denman Island receive sodium tetraborate at the rate of 10 pounds to the acre. He also believes that there is evidence of boron deficiency for apples in the Courtenay district. J. Gillingham, of Gordon Head, is of the opinion that his apple orchard soils are deficient in boron, but, as yet, nothing definite has been proven. The opinion is expressed that boron deficiencies may be responsible for the poor stands of alfalfa and clover on Vancouver Island. Again, the soils of the Olympic Peninsula, Washington, U.S.A., have been shown to be very deficient in boron. While, not in British Columbia, these soils belong to the Pacific Coast zone and are geologically similar to those of Vancouver Island.

The data already discussed relative to the Fraser Valley soils indicate that many of the soils are adequately supplied with available boron. Nevertheless, some appear to have barely enough, and, under the influence of cultivation, cropping, liming, etc., one may expect deficiencies to occur in crops, especially those with high boron requirements, such as alfalfa.

Doctor Brink has reported that in an experiment at Abbotsford the use of sodium tetraborate at the rate of 20 pounds per acre increased the yield and quality of alfalfa. For sugar beet seed production, Reifel (1944) states that boric acid, 15 pounds per 100 pounds of fertilizer, is included in the 6-30-15 mix and applied at seeding time.

Several instances have been noted at the University of British Columbia farm, where applications of sodium tetraborate have improved alfalfa and root crops. In the summer of 1947, suspected boron deficiencies were found in cabbages grown on the University horticultural plots. Here sodium tetraborate is applied at the rate of 30 pounds to the acre every three years.

In Washington, U.S.A., which adjoins British Columbia, Bauer, et al (1941), concluded that boron deficiency (Alfalfa Yellows) was prevalent in much of the 15,000 acres of alfalfa in Western Washington. Soil types on which the deficiency was most commonly observed were mainly in upland areas. Greenhouse studies and field trials showed that the deficiency in Washington may be corrected by applications of 50 to 60 pounds of sodium tetraborate per acre to silt and clay loams and by 30 to 40 pounds on the lighter soils.

Soils of the Interior Plateau (Zonal Complex):

The location of this zone can be obtained from the map in Chart II. Many of the soils are Brown soils and probably most of those analyzed fit into this group.

The majority of the samples analyzed are from the Okanagan, even though it is realized that this area has already been dealt with much more thoroughly than can be attempted in a general survey of British Columbia soils. They are included singly for the purpose of determining the extent to which the method of Berger and Truog (1944), which

employs a boiling-water extraction, agrees with that employed by Woodbridge (1940), who extracted with cold water. The results of this comparison, along with data concerning a few miscellaneous samples, are presented in Table IX.

A consideration of the data shows that the virgin soils all contain less than 0.5 p.p.m. available boron, ranging from 0.05 to 0.4 p.p.m., with an average of 0.16 p.p.m. Woodbridge (1940), in his studies, found that the values ranged from 0.09 to 0.33 p.p.m. These data show excellent agreement in spite of the fact that distinctly different samples were used. Woodbridge's data show a slightly lower level of available boron, which is as it should be. The latter also found that added boron penetrated deeper in light soils than in heavy soils, with a gradual decrease in boron content with increased depth. Judging from the data in Table IX, most of the element seems to be concentrated in the top 8 inches of surface soil, though in the case of No. 128, from Penticton, there seems to have been considerable penetration down to 24 inches. This does not wholly agree with Woodbridge's results, which show a uniform decrease in penetration in cases of all classes of soil down to 30 inches. It is believed, in this connection, that Woodbridge's samples were collected at a considerably longer period after the application of boron fertilizers than were those analysed by the writer. Again, Woodbridge sampled thinner layers of a uniform thickness, while in the case of the present investigation the thickness of the layers sampled ranged from 8 inches at the surface to 26 inches at

TABLE IX.- Boron Content and Related Data Pertaining to Soils of
the Interior Plateau (mostly Brown Soils considered)

Sample No.	Identity of Soil or Locality	Remarks	Depth	P.p.m. Avail-able Boron	% O.M.	pH
Selected:						
139	Penticton Si.	Virgin	0-8"	0.40	1.52	7.60
140	Summerland	"	0-8"	0.05	.53	7.30
141	"	"	8-15"	0.05	.08	7.30
142	Kelowna	"	0-8"	0.10	1.20	6.20
143	"	"	8-15"	0.10	6.90	6.50
127	Penticton Si.	30 lbs. boric acid, acre - once	0-8"	1.50	--	--
128	"	" " " " "	8-24"	0.40	--	--
129	"	" " " " "	24-60"	0.05	--	--
130	Glenmore c.	" " " " "	0-8"	0.70	--	--
131	"	" " " " "	8-24"	0.20	--	--
132	"	" " " " "	24-60"	0.10	--	--
133	Oyama black earth	" " " " "	0-8"	1.50	--	--
134	" " "	" " " " "	8-24"	0.05	--	--
144	Kelowna	Per tree per yr. - 1 oz. boric acid	0-8"	1.25	--	--
145	"	4 oz.	0-8"	4.20	--	--
146	"	1 lb.	0-8"	1.75	--	--
147	"	Discontinued 1943 2 lb.	0-8"	1.75	--	--
148	"	Discontinued 1941 4 lb.	0-8"	0.70	--	--
149	"	Cult. - No treatment	0-8"	0.70	1.52	7.00
150	"	" " "	8-15"	0.15	0.66	7.10

Continued

TABLE IX (continued)

Sample No.	Identity of Soil or Locality	Remarks	Depth	p.p.m. Available Boron	% O.M.	pH
<u>Miscellaneous</u>						
184	Kelowna	Cultivated	0-6"	0.00	3.32	6.9
177	Kamloops	"	"	0.20	2.74	7.3
178	"	"	"	0.40	4.69	7.2
179	"	"	"	22.00	7.16	6.7
180	Armstrong	"	"	0.80	2.04	5.9
181	Vernon	"	"	0.40	6.76	7.8
182	"	"	"	1.25	7.04	6.7
183	"	"	"	0.80	6.85	--
187	Alexandria	"	"	0.25	1.93	7.9
188	Quesnel	"	"	0.43	2.88	7.7

Si. - Silt, c. - clay

depth.

In common with Woodbridge, the writer's data demonstrate that, in boron fertilized soils, there is no consistent correlation between the amount of boron compound applied and the amount found present by analysis. For example, in No. 145, which received 4 ounces of boric acid per tree per year, the boron content is 4.20 p.p.m., while in No. 146, which received 1 pound per year, the content is only 1.75 p.p.m. Woodbridge states that this may be accounted for, at least in part, by the type of soil, by the method of application (scattering by hand), or by the method of sampling (four points about a tree).

Nine miscellaneous cultivated samples, the histories on which are scant, have available boron contents ranging from 0.0 to 22.0 p.p.m., with seven analyzing 0.8 p.p.m. or less. The extremely high value for No. 179 suggests sampling shortly after uneven distribution of a boron fertilizer. As far as the writer is aware, the crops grown in this soil display no signs of boron toxicity.

The foregoing data agree well enough with the various investigations and field observations, which show soils of the zone under discussion to be low in available boron. All of the virgin samples and six of the miscellaneous samples have contents below the minimum of 0.5 p.p.m. established by Woodbridge (1937).

Miscellaneous Samples:

These samples consist of a collection selected from those sent in to the Soils Laboratory, University of British Columbia, during the past fifteen years for routine soil testing. The histories on some are scant, but it is assumed that most are cultivated, and, in some instances, represent relatively small areas. The probability of boron fertilization, especially in the latter cases, is high. Nevertheless, such samples should give a general picture of this class of land in respect to available boron. Furthermore, some of the samples include localities not dealt with previously and these may serve to round out the data on the boron status of British Columbia soils.

The results are shown in Table X. Of the 29 surface samples analyzed, 28 have an average available boron content of 1.42 p.p.m., with values ranging from 0.0 p.p.m. to 3.2 p.p.m. The remaining sample (No. 179), from Grand Forks, contains 12.0 p.p.m. This high figure indicates the influence of boron fertilization, which is practised extensively in this area.

No. 151 from Saanichton contains practically no available boron. The pH of this sample is 7.8, and the appearance of white particles in the soil indicates the presence of lime. The possibility of boron fixation by over-liming, which will be discussed in a later section, is not out of the question.

The samples from the Lower Mainland, with the exception

TABLE X.-
Available Boron Content and Related Data
Pertaining to Miscellaneous Surface Samples

Sample No.	Locality	Remarks	P.p.m. Available Boron	% O.M.	pH
151	Saanichton	Well-limed	0.00	4.83	7.8
<u>LOWER MAINLAND</u>					
152	Gambier Isl.		2.20	9.49	6.0
153	Dollarton	Gravelly loamy sand	3.20	10.50	5.0
154	Vancouver	Heavy clay	1.10	5.73	5.6
250	"	Clay loam	1.20	13.41	4.9
251	"	Clay loam	1.10	1.84	5.4
252	"	Loamy	0.75	17.14	5.70
253	Cloverdale	Clay-like	1.00	0.65	7.60
254	Matsqui	Heavy clay	1.00	3.33	6.70
255	Vedder Crossing		1.00	6.36	5.80
256	Chilliwack	Clay	1.80	5.56	5.30
257	"	Fine silty sandy l.	0.60	5.92	5.30
258	Mission	Loam	0.40	5.00	6.58
<u>SOUTH INTERIOR AND S.E.</u>					
259	Lytton	Gravelly sandy loam	1.25	2.48	6.50
260	"	" " " "	1.10	4.20	6.35
263	Princeton	Wheat soil	1.50	11.62	5.60
269	Knutsford	Wheat soil	1.50	6.44	6.30
264	Sidmouth	Gray silt	0.50	--	5.10
265	Bridesville	Wheat soil	0.20	5.64	6.10
179	Grand Forks		12.00	1.79	6.40
266	Erickson		0.00	6.57	7.40
267	Golden		0.00	2.66	8.40
268	Golden		0.20	2.65	8.20
<u>CENTRAL INTERIOR</u>					
261	Buffalo Lake	Black sandy loam	0.65	2.51	6.80
262	" "	Black clay	1.70	8.32	6.40
270	Streatham	Wheat soil	1.25	7.53	6.00
280	Quick Sta.	" "	1.30	7.60	--
290	North Newlands	" "	1.25	6.80	5.3
291	Fort Nelson		1.40	2.51	4.3

of Nos. 258 and 257, seem well supplied with available boron. It is significant that the last mentioned are light-textured soils. In connection with Nos. 152 and 153, the high content of 2.2 and 3.2 p.p.m. is interesting. Their proximity to the sea and high organic matter content suggest applications of seaweed which should be high in boron.

A considerable range is shown in the available boron content of samples from the Southern Interior and South-eastern British Columbia. Those from the South-east are low, which is in keeping with field observations. On the other hand, those from Lytton, Princeton, and Knutsford are considerably higher, having available contents in excess of 1.0 p.p.m.

The soils from the Central Interior likewise have available boron contents in excess of 1.0 p.p.m., with the exception of sample No. 261 from Buffalo Lake. This soil, in addition to having a coarse texture, lies in a zone (the Interior Plateau) where boron deficiencies have been observed. It is interesting to note that the samples of soil from wheat lands were collected more than fifteen years ago and the available boron content may now be considerably less.

The single sample from Fort Nelson has a content of 1.40 p.p.m. This supports earlier data demonstrating the relatively high available boron content of North-eastern British Columbia soils.

To summarize, most of these data agree fairly well with those obtained earlier. Seemingly high values for certain of the Lower Mainland soils may be due to boron fertilization.

Influence of Liming on the Available Boron
Content of Some Fraser Valley Soils

The fixation of boron by over-liming the soils is a phase of its availability that has received widespread attention. The existence of the injurious effect of liming has been confirmed in the case of cauliflower and radish, by Wolf (1940), beet, by Cook and Millar (1940), mangolds, by Brown (1941), and a variety of crops, by Midgeley and Dunklee (1940).

Fraser Valley soils, with their medium to high acidity, are frequently limed. It was considered important, therefore, to find out what effect liming has on the boron availability of the aforementioned soils.

Method:

Accordingly, a peat, a Ladner clay, a Lynden silt loam, and a U.B.C. upland soil, were selected. After the soils were air-dried, their pH's and available boron contents were determined. Four 200 gram aliquots of each were placed in metal containers and increasing amounts of hydrated lime ($\text{Ca}(\text{OH})_2$) added to give pH values ranging from the original to well above neutrality. Sufficient water was applied to give a desirable consistency. Following this, the tins with their contents were weighed and placed in an incubator at 28° Centigrade for two weeks. At the end of the incubation period the soil was removed and air-dried after which the pH and available boron content were determined.

Discussion:

The results are given in Table XI. Considering all four

TABLE XI.-The Effect of Liming on the Available Boron
Content of Some Lower Fraser Valley Soils

200 gms. Sample	Gms. Ca(OH) ₂	Tons/Acre	pH	p.p.m. Available Boron
Peat	0	0	5.60	7.0
"	1	2.5	6.05	6.0
"	3	7.5	6.65	5.6
"	5	12.5	7.20	2.8
"	7	17.5	7.75	2.8
Ladner Clay	0	0	6.0	0.5
"	.25	1.25	6.85	0.6
"	.5	2.50	7.40	0.6
"	1.0	5.0	7.85	0.3
"	1.5	7.5	8.25	0.3
Lynden Silt Loam	0	0	5.85	0.5
" " "	.25	1.25	6.40	0.4
" " "	.50	2.50	6.80	0.4
" " "	1.0	5.0	7.15	0.1
" " "	1.5	7.5	7.50	0.1
U.B.C. Upland	0	0	4.60	0.7
" "	.25	1.25	5.00	0.5
" "	.5	2.50	5.45	0.5
" "	1.0	5.00	5.80	0.55
" "	1.5	7.50	6.45	0.50
" "	2.0	10.0	6.70	0.45
" "	2.5	12.5	7.30	0.25
" "	3.0	15.0	8.00	0.2

it is evident that, once a pH of 7 (or thereabout) is reached, there is a sharp drop in available boron. In the case of the Ladner clay, the drop does not occur until a pH of 7.4 is reached, and then it is not so pronounced as in the case of the Lynden silt loam and U.B.C. upland. This behaviour of the Ladner clay partially supports the findings of Midgeley and Dunklee (1940), who found that a clay of pH 6.1 did not fix added boron when over-limed. In the present investigation, however, when enough lime is added, the boron is fixed. One might conclude from this that the amount of lime added, as well as the pH reached, is an important factor.

The raw peat which has a high available boron content still seems well supplied even after heavy liming. Midgeley and Dunklee (1940) showed that only well decomposed organic matter would fix boron completely in the presence of lime. The peat under investigation is, at the best, only partially decomposed, which might offer an explanation for incomplete fixation.

The fact that the boron content remains approximately at the same level and then drops in the vicinity of neutrality, agrees with the findings of Wolf (1940), who showed that plants grown in a series of soils to which increasing amounts of lime had been added took up about the same weight of boron until a pH of 7 was exceeded, following which the weight absorbed by the plant decreased rapidly. This observation does not imply, however, that plants will not evidence deficiency symptoms until neutrality is exceeded.

It has been shown at the Experiment Station, Kentville, Nova Scotia (1934-5-6), that limed plots, in general, had a slightly higher available boron content than unlimed plots. In no case did the pH exceed 6.3, yet the limed plots supported apple trees showing drought spot, or cork, or both, while the unlimed plots with a lower available boron content supported healthy trees.

The findings of Reeve and Shive (1944) may have some bearing on the problem; namely, that every plant has an optimum calcium boron ratio. For some, it is quite high, while for others with a high boron requirement, it is low. Addition of lime to the soil may cause the ratio to be upset within the plant unless boron additions are made to the soil in conjunction with liming.

From the foregoing discussion, it would seem that the boron content of many of the Lower Fraser Valley may drop considerably when liming is practised.

Reference is made once more to Table VIII, where it is shown that many of the virgin soils from this area have available boron contents ranging from 0.5 to 0.8 p.p.m. Such soils, when limed, would probably benefit from boron additions.

Insofar as posts are concerned, their boron content and stage of decomposition are so variable that it is hard at this point to draw any conclusions regarding liming. Yet it is well, once again, to mention Harris (1943), who found

a response to boron additions in plants grown in a well-limed peat.

At best, this study is only a very preliminary one and further work will be necessary in this respect. It does, however, make one aware of the fact that such an investigation is required in order to understand fully the question of available boron in Fraser Valley soils.

DISCUSSION

Certain data from Tables VI to X, inclusive, are summarized in Table XII. Averages have been calculated for total and available boron according to geographic subdivisions of soil zones.

A significant feature relative to data in Table XII is the high average total boron content of over 60.0 p.p.m. for Peace River soils, which is twice the next highest contained in soils from Terrace and Vancouver Island. The Okanagan soils follow with a total boron content of 25.0 p.p.m., while the Central Interior and Lower Fraser Valley samples are the lowest. It is realized that too much importance should not be attached to slight variations, since, in some cases, only a few samples are averaged. The salient point is that the total boron content of Peace River soils exceeds all others by a wide margin.

The origin of Peace River soils has quite frequently been a debatable point. Certain authorities maintain that these soils originated from the Rockies in the west, while

TABLE XII.-

A Summary of Certain Data from Tables VI and X,
inclusive.

ZONE	Surface and Parent Material		Surface	
	p.p.m. Boron Total		p.p.m. Boron Available	
	No. Samples	Av.	No. Samples	Av.
<u>DEGRADED BLACK</u>				
Peace River	4	70.6	2	2.42
Central Interior	8	21.0	9	1.16
<u>GRAY WOODED</u>				
Peace River	5	60.9	2	1.45
Central Interior	8	17.9	11	0.65
<u>PACIFIC COAST</u>				
Terrace	3	31.5	5	0.44
Vancouver Island	2	33.8	9	0.24
Fraser Valley	23	14.8	38	0.80
<u>INTERIOR PLATEAU</u>				
Okanagan	2	25.0	11	0.39
<u>MISCELLANEOUS</u>	--	--	29	1.42
<u>FRASER VALLEY PEATS</u>	--	--	8	5.20
TOTALS	55	--	124	--

others adhere to the theory that the parent material is of Keewatin glacial origin from the east.

Okanagan soils are of Rocky Mountain origin and the two samples analyzed show an average total content of 25.0 p.p.m., which is only about one-third the value obtained for Peace River soils. The evidence is scant, but it appears to support the belief that the latter soils originated, not from the west, but from deposition related to Keewatin glacial sheets from the east.

Another observation of note is the low average total boron content of 14.8 p.p.m. for Lower Fraser Valley soils.

The data presented for the available boron content of surface soils show those from the Peace River area to have the highest content. Soils from Terrace, the Okanagan Valley, and Vancouver Island, are lowest, all containing less than 0.5 p.p.m. available boron. The Lower Fraser Valley and Central Interior soils come in between with available boron contents ranging from 0.65 to 1.16 p.p.m.

In both the Degraded Black and Gray Wooded zones, the Peace River soils are well supplied with available boron. Probably much of the high total content is absorbed in the abundant clay colloids. Soils formed from such parent material should be able to undergo considerable cropping and cultivation and still maintain a reasonable level of available boron.

The Degraded Black soils of the Central Interior, with

an available boron content of 1.16 p.p.m., seem to have a sufficiency. The average of 0.65 p.p.m. for the Gray Wooded soils of this area is low. It has already been mentioned that crops grown in this zone often require boron fertilization.

The soils from the Pacific Coast zone all have average available boron contents below 1.0 p.p.m. The low values for Terrace and Vancouver Island soils have been substantiated to a certain extent by field observations. The extremely low average of 0.24 p.p.m. for Vancouver Island is startling and indicates that the area merits more thorough investigation. The pH values for Terrace and Vancouver Island soils are 5.7 and 5.3, respectively. This fairly high acidity, combined with a heavy annual precipitation, probably causes the available boron to be rapidly leached from the soil as boric acid.

The figure of 0.8 p.p.m. available boron for the Lower Fraser Valley soils is quite surprising when one refers back to the low total boron content of 14.8 p.p.m. It is possible, in the lowland soils, that most of the total boron is held in the soil colloids and does not exist as insoluble rock or mineral particles. One is tempted to suggest that, although the total boron content is low, much of it is in a reserve form.

For coarser textured, excessively drained soils, the foregoing would not apply. Indeed, it is in soils of the

last mentioned category that boron deficiencies are most likely to occur.

Berger and Truog (1945) have shown that, in Wisconsin, soils having a pH below 7 and organic matter in excess of 2 per cent are generally well supplied with available boron.

The average organic matter content for Fraser Valley soils, as obtained from Table VIII, is 7.34 per cent, which is quite high. In this respect it is noteworthy that peats, which are practically all organic matter, seem to be high in available boron. A soil type, then, such as Ladner clay, which often is mixed with, or lies adjacent to, peat deposits, should have a high available boron content. While realizing the fine texture and seemingly high organic matter content of many of the Fraser Valley soils, one must not forget that cropping and certain other practices influence the available boron supply. Indeed, boron deficiencies have been reported in Ladner clay at Matsqui, B.C.

Extensive cultivation, combined with a high annual precipitation and a low average pH of 5.46, may result in drastic losses through leaching. Liming, as shown during this investigation, seems to decrease the supply of available boron in Fraser Valley soils.

Little need be said concerning the soils from the Interior Plateau since the fact that they are generally deficient in boron is well known. Suffice to say, the average of 0.39 p.p.m. available boron appears to tie in well with

field observations and other experimental data.

In concluding, it is well to mention the work of Whetstone, et al (1942), who have shown that the soils of the Pacific North-western States are derived from materials inherently low in boron. They suggest that the Okanagan Valley is also included in this area. Indeed, from the data to hand, one is inclined to believe that, not only the Okanagan Valley, but all of British Columbia, with the exception of the Peace River district, could be grouped with the Pacific North-western States in respect to boron status.

SUMMARY

1. The methods of Colwell (1943) and Berger and Truog (1944) for determining available boron in soils were compared. Excellent agreement is shown.
2. Total and available boron were determined in soils representing four major soil zones of British Columbia.
3. Soils from the Peace River Block, regardless of their zonal classification, show an extremely high total boron content, while soils lying to the west of the Rocky Mountains contain much less.
4. Fraser Valley soils display a low total boron content.
5. Available boron appears to be highest in the Degraded Black soils from the Peace River Block, Fraser Valley peats, and certain Ladner clays.

6. Virgin Gray Wooded soils from the Central Interior are reasonably well supplied with available boron, while the content of cultivated soils of this zone indicates a sharp decline.

7. Soils from Terrace, Vancouver Island, and the Okanagan, as a rule, seem to be deficient in available boron.

8. The available boron content of Fraser Valley soils appears to be well above the average in many instances, while in others, the content appears dangerously low. Light-textured, excessively drained types, appear to be the ones most likely to be lacking in available boron, although heavy-textured soils may also evidence deficiencies.

9. With the data accumulated, it is difficult to arrive at any definite conclusion regarding the effect of organic matter and pH on the available boron content of British Columbia soils.

10. On the basis of a laboratory experiment, heavy liming seems to lower the available boron content of certain Fraser Valley soils.

PART II.- INVESTIGATIONS CONCERNING THE POSSIBILITY OF
USING TOURMALINE ROCK AS A BORON FERTILIZER

INTRODUCTION

The Consolidated Mining and Smelting Company in their operations at the Sullivan Mine, Kimberley, B.C., find it necessary to remove large quantities of a hard black cherty rock in order to reach the ore. This waste product, on microscopic examination, was found to be relatively high in tourmaline crystals imbedded in quartz. Dr. H. Warren, of the Geology Department, University of British Columbia, suggested that this material, when finely ground, may have possibilities as a boron fertilizer. If sufficiently high in available boron, the rock should have certain advantages over the usual boron fertilizing materials. For instance:

- (1) The rock would supply the soil with boron in a slowly available form.
- (2) Enough could be applied so that even distribution would be facilitated.
- (3) The material may contain certain other beneficial minor elements.
- (4) The rock could be used as a cheap inactive filler in fertilizer mixes, thus adding boron and perhaps other minor elements.

Eaton and Wilcox (1939) experimented with unweathered and weathered heavy black rock obtained from the American Tin Company, at the Cojalco Tin Mine near Riverside, California. This is similar to the Kimberley waste. The

weathered material contained 1.17 per cent total boron, while the unweathered rock analyzed 1.45 per cent. Tomato plants were grown in both materials. Those in the weathered rock were normal and vigorous, while those in the unweathered material were severely injured. Katalymov (1941) concluded that crude tourmaline is unsuitable as a boron fertilizer without chemical treatment; such, for instance, as fusion with lime.

EXPERIMENTAL

This preliminary investigation was undertaken merely for the purpose of ascertaining whether or not a detailed research programme would be justified.

A total analysis by the method of Treadwell and Hall (1945) gave the B_2O_3 of the unweathered rock as 3.87 per cent, or, when expressed as boron, 1.2 per cent. The available boron in a 200 mesh sample was found to be 30.0 p.p.m.

To determine whether or not 30.0 p.p.m. of boron is actually available to plants, increasing amounts of the 200 mesh rock were added to 600 gram aliquots of washed quartz. A series of quartz controls containing added boron in concentrations up to 0.5 p.p.m. was provided. The test was performed in accordance with the biological analysis of Colwell (1943), as previously discussed. The results of the experiment are presented in Table XIII. Figure 3 shows the appearance of the cultures 35 days after planting.

TABLE XIII.-

Effect of Different Concentrations of
Tourmaline Rock on Sunflower Plants Growing
in Quartz Sand

QUARTZ SAND CONTROLS					
p.p.m. Boron Added			Average Age Value		
0.0			15 days		
0.05			21 "		
0.10			27 "		
0.30			31 "		
0.50			34 "		

gms Tourmaline Rock Added	Weight Quartz Sand	Tons per Acre	Age Value	p.p.m. Boron (Colwell)	p.p.m. ^x Boron (Berger and Truog)
0.0	500	0	15	0.00	0.00
0.5	500	1	19	0.03	0.03
1.0	500	2	23	0.07	0.06
2.0	500	4	26	0.10	0.12
4.0	500	8	30	0.20	0.24
6.0	500	12	32	0.35	0.36

^xAnalysis of the rock by the method of Berger and
Truog (1944) gave 30.0 p.p.m. of available boron.

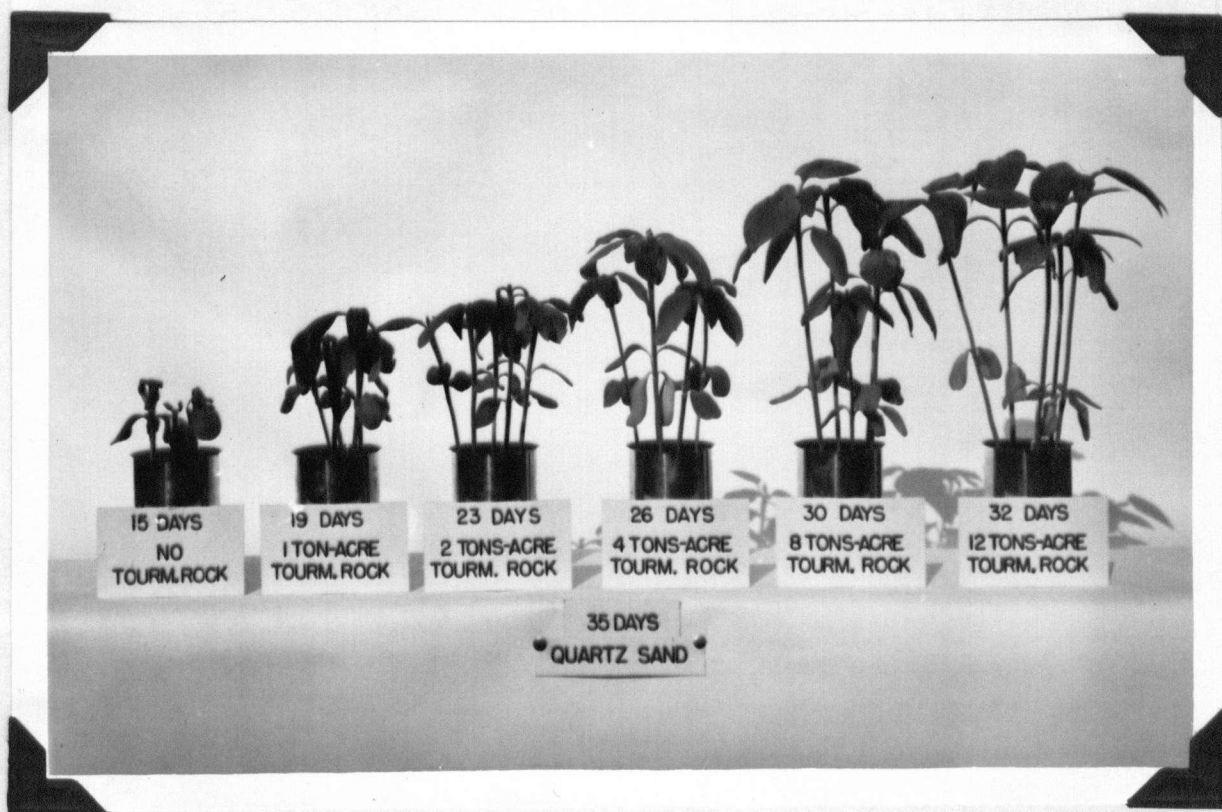


Fig. 3

Sunflower plants growing in quartz sand to which increasing amounts of tourmaline rock have been added. The number of days shown on the card, along with the amount of tourmaline rock, refer to the age of the plants when boron deficiency symptoms first appeared. All cultures are 35 days old.

From the data submitted, it may be seen that the Colwell (1943) and Berger and Truog (1944) methods of analysis check very nicely. Thus, the 200 mesh sample under test is concluded to contain 30.0 p.p.m. of immediately available boron. Assuming that the solubility in a soil would correspond to that in quartz, an application of 12 tons ground rock per acre would be necessary to provide 0.35 p.p.m. of available boron. At a minimum cost of \$3.80 per ton, such an application would appear to be prohibitive.

The rate at which ground tourmaline rock becomes available in quartz or soil upon successive leaching with water has not been determined, but is a point worthy of consideration.

In order to determine the response to applications of tourmaline rock to light-textured soils, sufficient of the ground material was added to Munroe loamy sand containing 0.05 p.p.m. of available boron to give concentrations varying from 0.05 to 5.05 p.p.m.

The results of the experiment are shown in Table XIV. An interesting observation is that, before a level toxic to sunflower plants is reached, about 43 tons or more per acre of the rock are necessary, when calculated on a field basis. It is to be observed also, that, under the conditions of the experiment involving a very light soil, a concentration of available boron between 0.55 and 1.30 p.p.m. appears to be best for the sunflower plant.

TABLE XIV.--

The Effect of Various Concentrations of
Tourmaline Rock on Sunflower Plants Growing
in Munroe Loamy Sand

Gms. Tourmaline Rock Added	Wt. Munroe l.s.	Tons Acre	p.p.m. Boron	Observations
0	600	0	0.05 ^x	Deficiency at 20 days
10	590	17	0.55	Healthy growth
25	575	43	1.30	Slower growth
50	550	86	2.55	Definite injury
75	525	129	3.80	Four plants killed
100	500	172	5.05	No growth

^xInitial available boron content of Munroe loamy sand.

CONCLUSIONS

From the foregoing experiment it appears that 12 tons per acre of tourmaline rock are necessary in very sandy soils to increase the available boron content by 0.35 p.p.m. Under field conditions, especially in heavy soils, the application would probably have to be even greater. Twelve tons of the material would cost \$45.00. Considering the fact that 20 pounds of sodium tetraborate per acre of mineral soil theoretically increase the boron content by approximately 1.0 p.p.m. for only a slight fraction of the above price, a detailed research programme hardly seems justified.

Before abandoning the problem altogether, however, studies conducted to investigate the boron reserve of the tourmaline rock may be advisable. Again, research concerning the feasibility of using the material as a filler in fertilizer mixes has certain possibilities.

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