A STUDY OF TOTAL AND WATER-SOLUBLE BORON IN OKLAHOMA SOILS

By

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Several reports have been published about boron deficiencies in soil and its relation to certain types of diseases, or failure of plants to produce good crops. Considerable work has been done on the problem of boron requirements for normal growth, but very little work has been done to determine how much available boron should be in the soil for the optimum growth of crops. Almost no work has been done to find out how much boron is present in the soils of different areas or to predict how well different crop plants will grow on soils with a low boron content.

The purpose of this investigation was to analyze soils, from various locations in Oklahoma, for total and available boron to determine if some areas might benefit from boron fertilization. The object was to determine how much boron is available for plant use; how it is distributed in the soil profile; how cropped soils compare with virgin soils; and attempt to show the relation between the amounts of boron found in the soils and expected crop response.

REVIEW OF LITERATURE

Very little information was obtained from the literature which would help with the solution of this problem. In a few widely scattered areas, some work has been done on evaluating soils for their boron content. Jordan and Powers (20)[1] made a rather comprehensive study of the boron content of Oregon soils. They found that crops growing on medium textured soils containing less than 0.50 ppm. of available boron usually resulted in a deficiency; soils containing from 0.50 to 0.75 ppm. available boron was optimum for plant growth, and more than 0.75 ppm. was excess or toxic. They stated that lighter textured sandy soils, having a lower base exchange capacity, have a somewhat lower concentration of soluble boron and the heavier textured soils and those that are basic in reaction have a higher concentration due to the higher colloidal content.

Rogers (27) made a study of the coarse textured soils of Alabama in relation to the need of boron fertilization for legumes. He found that when legumes, which usually require a rather high concentration of available boron for good growth, were grown on coarse textured soils, the requirements were much less than that needed on the finer textured soils. He attributed this to the fact that coarse textured soils usually have a low calcium supply and a low base exchange capacity.

Schaller (28) made a study of the boron content and requirements of West Virginia soils and stated that many of the soils in West Virginia approach the lower boron limits for maximum alfalfa growth, although most soils have sufficient available boron to prevent plant deficiency symptoms. His data indicate that the available boron content

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[1] Numbers in parentheses refer to references cited on p. 44-45.

of the subsoils is lower than that of the plowed layer, and that this would cause a shortage of available boron on badly eroded soils. He also claimed that soils lowest in boron content have been effected by strong leaching processes, such as that occurring on soils derived from acid shale and sandstone.

DeTurk and Olson (13), in a study of boron in Illinois and Georgia soils, found that the water-soluble boron in the soils of Illinois ranges from 0.20 to 1.22 ppm. and in Georgia from 0.01 to 0.65 ppm. They found that symptoms of boron deficiency occurred in lespedeza, alsike clover, and red clover when the amount of available boron in the soil was less than 0.50 ppm. DeTurk and Olson also analyzed these soils for total boron, but could not find any relationship between the total boron in the soils and the water-soluble fractions. The total boron in the Illinois soils ranged from 18 to 47 ppm. and that in Georgia from 5 to 52 ppm. They found ratios between total and water-soluble boron ranging from as low as 17 up to 141.

Cook and Millar (11), in a study of Michigan soils in relation to the occurrence of heart rot in sugar beets, reported that there is no correlation between the appearance of this condition and the borate content of the soil, but that there is a correlation between the appearance of this disease and the active calcium content of the soil. They also found that when a very porous layer of subsoil occurred beneath the topsoil, excessive leaching would be inducive to boron deficiency, due to the fact that boron is leached out as fast as it is made available, and thus is lost for crop use.

Midgley and Dunklee (22) reported instances of boron deficiencies in soils of Vermont and are of the opinion that excessive applications of lime on acid soils is the cause of boron deficiencies in crops grown in that region. Naftel (24) states also that liming decreases the water-soluble boron content of soils and that the extent of decrease depends on the amount of lime that is applied.

Olson and Berger (25) state that calcium ions have no effect on the fixation of boron in the soil, but that it is the increase in alkalinity that causes the fixation by certain clay minerals in the soil.

Very little literature was found in regard to analytical methods for determining total and water-soluble boron in soils. Berger and Truog (5) described a method for determining total and water-soluble boron in soils and plants by the use of quinalazarin. A method for total boron has been described by Truog (29) in which the soil is fused with sodium carbonate, leached with water and acid, the boron removed by distillation with methyl alcohol, and determined using quinalazarine in a concentrated sulfuric acid solution.

DeTurk and Olson (13) described amethod for the determination of total boron in soils in which a strong solution of potassium hydroxide is used to fuse the soil instead of sodium carbonate as in Truog's (29) method. Their method is supposed to do away with the necessity of distilling the methyl borate from the solution.

Naftel (23) described a colorimetric method for determining water-soluble boron. The soil is refluxed with hot water to extract the boron from the soil, the filtrate evaporated twice using oxalic acid and turmeric as reagents to produce a color, the intensity of which can be compared with standard solutions.

Haas (17) recommended Naftel's method of determining water-soluble boron, and described the procedure in more detail than appeared in Naftel's paper.

ANALYTICAL METHODS FOR WATER-SOLUBLE AND TOTAL BORON IN SOILS

Boron-free glassware is the first requirement in the determination of water-soluble and total boron, with the use of glazed porcelain evaporating dishes for evaporating the solutions. Previous studies conducted in the soils laboratory of the Oklahoma A & M College indicated that the method proposed by Berger and Truog (5) had many objectionable features; consequently, a procedure described by Naftel (23) was studied and reproducible results were obtained using standard solutions and soil samples. The details of this method are as follows: Twenty grams of air dry soil that has been pulverized to pass through a 40 mesh sieve is weighed to a 200ml. boron-free erlenmeyer flask, 40 ml. of distilled water added, and the flask connected to a reflux condenser. The water-soil mixture is boiled for five minutes, cooled, and the suspension transferred to a centrifuge tube, and centrifuged to obtain a clear solution. An aliquot is placed in a porcelain evaporating dish, made alkaline with 5 ml. or more of a 0.10 N calcium hydroxide suspension, and then evaporated to dryness on a steam plate or water bath.

Add 1 ml. of a saturated solution of oxalic acid containing 20 percent of concentrated hydrochloric acid and 2 ml. of a 1.0 percent solution of turmeric dissolved in 95 percent ethyl alcohol to the dry residue in the evaporating dish. Rotate the dish so that the reagents come in contact with all residue, and evaporate to dryness over a water bath at a temperature of 55°C with no deviation greater than plus or minus 3°C.

On reaching the drying point, a reaction takes place between the oxalic acid, turmeric, and borates present which forms a red dye called rosocyanine.* The intensity of the color produced is directly proportional to the amount of boron in the aliquot.

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*$CH_2(CO\text{-}CH\text{-}CH\text{-}C_6H_3(OH)OCH_3)_2$ + $(CO_2H_2)_2.2H_2O$ + B_2O_3 = an isomeric rosocyanine (6).
(turmeric solution) (oxalic acid)

When the drying point is reached, continue heating for 30 minutes, remove and cool. The red colored residue is taken up in 95 percent ethyl alcohol, transfered to a centrifuge tube and centrifuged to obtain a clear solution. It is then made up to a suitable volume with ethyl alcohol (50 ml. was used in this study) and the color intensity is compared with standards made from boric acid and treated in the same manner as the soil extract. A Fisher electrophotometer using a green filter, number 525 B, with the machine set at A was used to measure the intensity of the red color.

Standard boric acid solutions with a range of 0.02 ppm. to 0.64 ppm. of boron were prepared from a solution containing 1 ppm. of boron. The amount of boric acid needed to make a solution containing 1 ppm. of boron was so small that it would be difficult to weigh; consequently, a solution containing 100 ppm. of boron was made up first and then diluted to make a solution containing 1 ppm. of boron.

These standards were treated in the same manner as the soil extracts. Readings for each solution were obtained on the Fisher electrophotometer. These results were plotted on graph paper against the amounts of boron that were known to be present and a curve developed, from which it was possible to prepare a table which could be used to obtain the amounts of boron in the soil samples. The calibration curve is shown in Figure 1, and Table 1 contains information on the relation between the photometer readings and the boron content of the standard solutions.

The calibration curve shown in Figure 1 can be used to determine much smaller amounts of boron, but it was felt that a smaller amount than 0.01 ppm. of boron was not significant.

Table I. Readings and Approximate Amountsof Boron As Prepared From the Calibration Curve shown in Figure I.

Readings on Photometer	ppm. Boron	Readings on Photometer	ppm. Boron
5	0.01	66	0.26
10	0.02	67	0.27
14	0.03	68	0.28
18	0.04	69	0.29
20	0.05	70	0.30
25	0.06	72	0.31
30	0.07	73	0.32
31	0.08	74	0.33
35	0.09	75	0.34
37	0.10	76	0.35
40	0.11	77	0.36
43	0.12	78	0.37
45	0.13	79	0.38
47	0.14	80	0.39
49	0.15	81	0.40
50	0.16	82	0.41
53	0.17	83	0.42
55	0.18	84	0.43
56	0.19	85	0.44
58	0.20	86	0.45
59	0.21	87	0.46
60	0.22	88	0.47
62	0.23	89	0.48
63	0.24	90	0.49
65	0.25	91	0.50

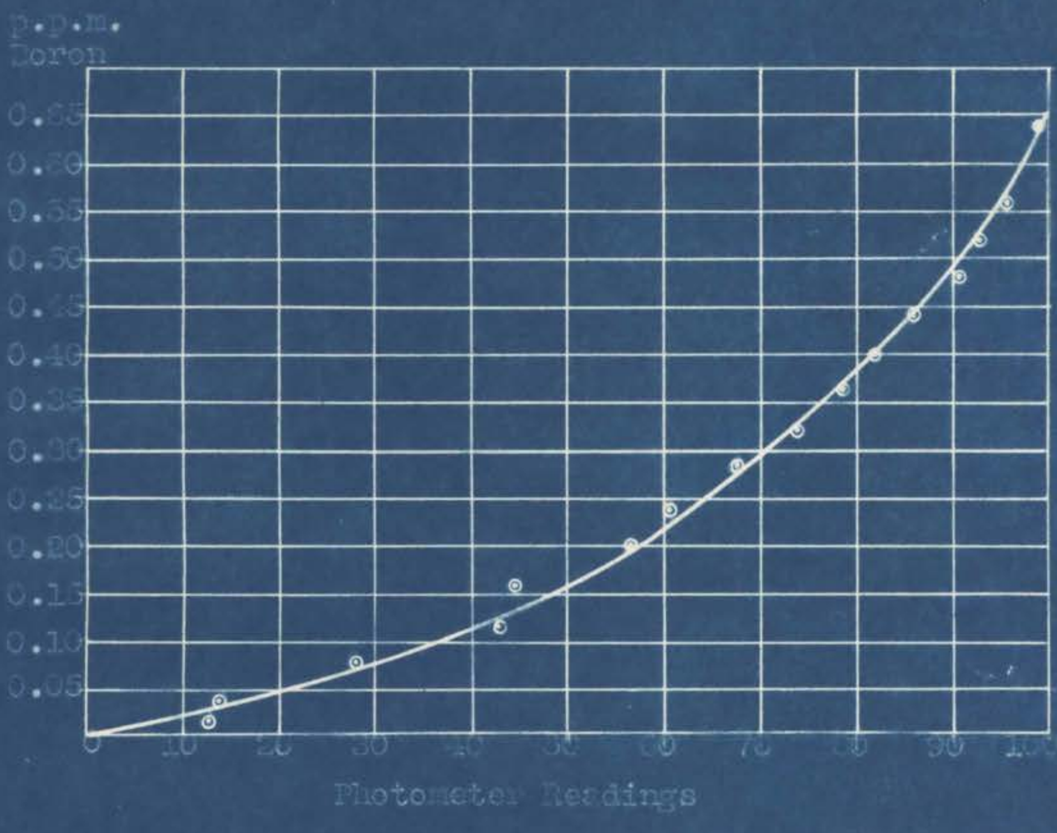

Figure 1. Calibration Curve of Boron Standards
Obtained With Electrophotometer

A modification of Truog's (28) method was used for the determination of total boron in soils. In this method the reagents employed were sulfuric acid and quinalazarine, with the sulfuric acid requiring a tedious standardization. Since hydrochloric acid works well with the reagents used in analyzing for water-soluble boron, it was decided to try a modification of the Truog method, using oxalic acid and turmeric in place of the sulfuric acid and quinalazarine for the measurement of total boron in the soil. A test was run to see if a known amount of boron could be recovered by this procedure and a 100 percent recovery was obtained.

The method used for determining total boron in soils was as follows: Three grams of anhydrous sodium carbonate was placed in a platinum crucible, 0.5 gm. of 100 mesh soil was added and stirred thoroughly into the sodium carbonate, leveling off the mixture when finished. The crucible was then placed on a triangle over a low flame and heated slowly for 10 minutes to drive off all moisture which might cause spattering. Then the temperature was gradually raised, complete fusion being obtained in 10 to 15 minutes. Pick up the crucible with nickel tongs and rotate melt gentlyto be sure that all of the soil has fused completely. After the fusion has cooled, place crucible in a boron-free beaker containing 50 ml. of distilled water, and cover with a watch glass. Add 4 to 5 ml. of 4N hydrochloric acid every few minutes (about three applications) and digest until the melt has completely disintegrated. Wash any solution adhering to the walls of the crucible into the beaker and adjust the pH of the solution to between 5.5 and 6.0 with 0.1 N NaOH and 0.1 N HCl using a spot plate and a suitable indicator.

Then transfer the contents of the beaker to a 500 ml. volumetric flask. After washing all residue into the flask, the volume should not be more than 150 ml. Fill to the mark with methyl alcohol and mix thoroughly. Remove a suitable aliquot from the solution after all soils have settled, and distill the alcohol and methyl borate formed from the reaction. Place the distillate in a porcelain evaporating dish, and after making alkaline with 5 ml. or more of a 0.10 N calcium hydroxide suspension, evaporate to dryness on a steam plate, or over a water bath. Develop the color and complete the analysis as recommended for water-soluble boron.

Naftel, in describing his method for the analysis for water-soluble boron in soils, recommended the use of Whitman No. 42 filter paper to obtain a clear solution. At the beginning of this study it was found that duplicate readings could not be obtained on the same standards, using filter paper. Clear solutions were obtained in centrifuge tubes, that were boron-free; consequently, it was apparent that some contamination was being obtained from the filter paper. Less time was also required to obtain clear solutions by centrifuging than by filtering.

EFFECT OF TIME OF REFLUXING AND TEMPERATURE OF EVAPORATION ON RECOVERY OF BORON:

It was thought that increasing the length of time the soils were refluxed might have some effect on the amount of boron removed from a soil. Only one soil was used in this study and the results obtained are shown in Table 2.

Table 2. Effect of Time of Refluxing on Amount of Boron Removed From a Soil

Sample No.	Time Minutes	Water-soluble Boron, ppm.
3063	5	0.22
3063	10	0.21
3063	15	0.23

It can be seen that there was very little difference in the amount of boron removed for the different periods of digestion, and the conclusion was drawn that 5 minutes refluxing removed all of the readily soluble boron from this soil.

It was also decided to study the effect of the water bath temperature during the final evaporation with the turmeric reagent on color formation. A boric acid standard containing 0.30 ppm. of boron was used in this test, and as can be seen in Table 3, varying the temperature as much as 5 degrees either way from the required 55°C reduced the amount of boron recovered.

Table 3. Effect of Increasing or Decreasing the Water Bath Temperature for Final Evaporation on Boron Recovery

Standard Used, ppm. Boron	Temperature °C	Boron Recovered, ppm.
0.30	50	0.22
0.30	55	0.30
0.30	60	0.26

SOURCE OF SOILS

The soils used in this study were obtained for the most part from field samples that came into the soils laboratory to be tested for reaction, available phosphorous, and exchangeable potassium. At the beginning of the investigation it was hoped that representative samples could be secured from each county. Although a number of counties were missed completely, a fairly good scattering of samples from all sections of the state was secured.

Soils from Craig, Dewey, and Cotton counties were brought in by R. O. Woodward of the Agricultural Extension Service.

Letters were written to each farmer or county agent, who sent in the samples, to determine the legal descriptions of the area from which the soils were collected and also the crops to be grown on them. A number of answers were received, but in many cases no legal descriptions were given.

EFFECT OF AIR-DRYING AND OVEN-DRYING ON THE WATER-SOLUBLE BORON CONTENT OF FIELD-MOIST SOILS:

At the beginning of this investigation, it was decided to make a study of the amounts of water-soluble boron found in soils under field-moist, oven-dry, and air-dry conditions to determine what effect, if any, drying has on the solubility of boron in the soil. Sixteen samples from Craig County, consisting of surface and subsoils and representing five soil types, were used for this study. The results of these analyses are presented in Table 4. An examination of this table shows that, with the exception of two soils, numbers 1 and 11, air-drying reduced the amount of water-soluble boron found in the surface soils when moist. Air drying of the moist subsoils reduced the amount of water-soluble boron in five soils; two were essentially the same, and in one case more was found. There does not seem to be an explanation for the latter case, but it may be that the soil particles did not disperse during the refluxing, thus not releasing all the soluble boron in the moist sample. Oven drying apparently does not reduce the amount of soluble boron as much as does air drying, in fact, in most cases more boron was found after oven drying than when the soils were moist. The reasons for this is not apparent, since one would expect that oven drying might fix more boron than air drying.

Because more water-soluble boron was found in most cases when the soils were moist than after air drying, it would seem to indicate that, when the soils are affected by a long period of drought, considerable boron may be fixed in a form unavailable for plants. Also, analyzing moist soils from the field might give a truer picture of boron availability than analyses made on air dry samples.

Three soil samples were brought in from Coal County when this investigation was almost completed, and since they seemed to be fairly moist it was decided to compare the results of analyzing them moist and air dry to see if the same results could be obtained as for those from Craig County. As can be seen by an examination of Table 8, more boron was obtained after the soils were air dried than when moist, and it was concluded that air drying does not fix boron in all soils.

Table 4. A Comparison of Air Drying and Oven Drying on the Water-Soluble Boron in Moist Soils Collected From Craig County in North Eastern Oklahoma:

Sample No.	Land User	Legal Description	Land Use	Surface or Subsoil	Soil Type	Soil Reaction	Water-Soluble Boron Field Moist ppm.	Oven Dry ppm.	Air Dry ppm.
1*	L. Harlan	SE$\frac{1}{4}$, SE$\frac{1}{4}$, SW$\frac{1}{4}$	Native	surf.	Parsons	mod. acid	0.19	0.22	0.17
2	Chelopar 3	30-29-21	Meadow	sub	loam	str. acid	0.96	0.14	0.02
3		NW$\frac{1}{4}$, NW$\frac{1}{4}$, BE$\frac{1}{4}$	crops	surf.	Parsons	sl. acid	0.36	0.22	0.13
4		31-29-21		sub	loam	mod. acid	1.01	0.19	0.10
5	Joe Tullis	SE$\frac{1}{4}$, SE$\frac{1}{4}$, NE$\frac{1}{4}$	crops	surf.	Hanceville	str. acid	0.20	0.19	0.10
6		3-28-21		sub	fsl.	sl. acid	0.16	0.20	0.05
7	J. Ward	SW$\frac{1}{4}$, SW$\frac{1}{4}$, SE$\frac{1}{4}$	Native	surf.	Bates	mod. acid	0.36	0.26	0.19
8	Wilde	26-28-20	Pasture	sub	loam	str. acid	0.08	0.10	0.02
9			crops	surf.	Parsons	mod. acid	0.30	0.36	0.16
10	Rex Inman	SE$\frac{1}{4}$, SE$\frac{1}{4}$, NE$\frac{1}{4}$		sub	loam	mod. acid	0.03	0.10	0.05
11	Vinita	34-26-20	Native	surf.	Parsons	mod. acid	0.14	0.27	0.13
12			Pasture	sub	si. loam	str. acid	0.01	0.13	0.06
13	Edd Bond	SE$\frac{1}{4}$, SE$\frac{1}{4}$, NE$\frac{1}{4}$	Native	surf.	Summit	str. acid	0.62	1.03	0.36
14	Vinita	16-25-21	Pasture	sub	clay	mod. acid	0.32	0.44	0.75
15		NW$\frac{1}{4}$, SW$\frac{1}{4}$	crops	surf.	Bates	str. acid	0.44	0.46	0.21
16	Bert Spaulding	16-26-20		sub	loam	str. acid	0.06	0.19	0.02
						Average-surf.	0.33	0.33	0.19
						-sub	0.44	0.20	0.13

*These soils were not a part of the regular laboratory samples, but were brought in for this study by R. C. Woodward of the Agricultural Extension Service.

WATER-SOLUBLE BORON IN OKLAHOMA SOILS

The main part of this study was made on soils that had been air dried before analysis. One hundred and sixty samples from 28 counties and representing a fair cross section of the state were analyzed for water-soluble boron. The results of the analysis of soils from the north eastern part of Oklahoma, as represented by Craig County, are shown in Table 4. These soils have been discussed previously, but not too much was said about the water-soluble boron obtained after air drying. These soils do not seem to be too well supplied with available boron. Available boron in the surface soils ranged from 0.10 to 0.36 ppm.

All but two samples were below 0.20 ppm. In almost every case the surface soils contained more available boron than the subsoils. Most of the subsoils are very deficimnt in available boron, with the exception of Number 14, which is a clay soil. This deficiency is quite likely the result of leaching processes due to the higher rainfall in this area.

East Central Oklahoma

Table 5 shows the results of the analysis of soils from east central Oklahoma, which are represented by four samples from Muskogee County, four from Sequoyah County, and two samples from Tulsa County. With the exception of one sample, which came from Sallisaw in Sequoyah County, these soils are well supplied with available boron. This soil, Number 4590, contained only 0.067 ppm. water-soluble boron. The soil was strongly acid in reaction, which may have had some influence on the low amount of available boron present (3). The available boron in the subsoils was somewhat lower than that in the surface soils.

Table 5. Water-Soluble Boron in Soils from East Central Oklahoma

Lab No.	Land User	Location	Surface or Subsoil	Crop	Soil Class	Soil Reaction	Water Soluble Boron ppm.
	Tulsa County						
4177	E. Pogue	Tulsa	surf.	----	Loam	mod. acid	0.54
4178			sub			neutral	0.48
	Muskogee County						
2924	E. Moore	Braggs	surf.	Corn	vsfl	sl. acid	1.90
2925			sub		vsfl	mod. acid	1.76
4463	H.E. Crauk	Muskogee	surf.	----	vsfl	sl. acid	0.52
4464			sub		-----	sl. acid	0.36
	Sequoyah County						
4192	V.A.T.P.	Vian	surf.	corn	si cl l	basic	1.10
4193	"	"	surf.	corn	si cl l	basic	1.14
4194	"	"	surf.	corn	si l	basic	0.85
4598	Co. Agent	Sallisaw	surf.	----	vfsl	str. acid	0.067

Abbreviations used in soil class: vfsl--very fine sandy loam; si cl l--silty clay loam; si l--silty loam.

North Central Oklahoma. The amount of water-soluble boron found in the soils from the north central Oklahoma is shown in Table 6. This part of the state is represented by samples from Osage, Kay, Noble, Garfield, and Payne counties. In most cases, the surface soils of this region are very well supplied with available boron. The surface soils from Kay County had from 0.44 to 0.96 ppm. of water-soluble boron and averaged about 0.60 ppm. The subsoils in these samples, for the most part, had more available boron than the surface soils, probably because they were less acid than the top soils.

The samples from Osage County were also fairly high in available boron. These samples show an interesting fact on the availability of boron in the soil in that, when the surface and subsoils have about the same reaction, the subsoils are lower in available boron, but when the surface soils are either more acid or basic in reaction than the subsoils, the reverse seems to be true (3).

The soils from Noble County had about the same amount of available boron as those from Kay and Osage Counties.

Only one surface sample was obtained from Garfield County, and this sample contained 0.56 ppm. of water-soluble boron, which is high enough for most crops.

The samples that were obtained from Payne County present a slightly different picture. Two soil types were analyzed, loamy and sandy soils. As is shown in Table 6, sandy soils do not as a rule have as much available boron as the more loamy soils. The loamy soils had from 0.70 to 2.30 ppm. of water-soluble boron in the surface soils and from 0.67 to 1.80 ppm. in the subsoils. Whereas, the sandy soils only had from 0.10 to 0.20 ppm. of water-soluble boron in the surface soils and from 0.04 to 0.12 in the subsoils.

Table 6. Water-Soluble Boron in Soils from North Central Oklahoma

Lab No.	Land User	Location	Surface or Subsoil	Crops	Soil Class	Soil Reaction	Water Soluble Boron ppm.
	Osage County						
2947			surf.	----	vfsl	sl. acid	0.87
2948			sub		L. s	sl. acid	0.81
2949	Ferd Doefel	Ponca City	surf.	----	vfsl	sl. acid	0.77
2950			sub		s cl l	neutral	1.14
2951			surf.	----	vfsl	basic	0.68
2952			sub		cl l	sl.basic	0.83
	Kay County						
3417			surf.	grain and	si cl l	sl. acid	0.44
3418	Chilocco Indian	Chilocco	sub	sorghum	si cl l	neutral	0.94
3429	School		surf.	corn	si l	mod.acid	0.61
3430			sub		si cl l	neutral	0.52
3435			surf.	corn	si l	mod.acid	0.65
3436			sub		si cl l	sl.acid	0.60
3443			surf.	grain and	loam	sl.acid	0.63
3444			sub	vetch	loam	sl.basic	0.63
3445			surf.	grain and	si l	mod.acid	0.96
3446			sub	vetch	si l	sl.acid	1.04
3447			surf.	alfalfa	si l	sl.acid	0.75
3448			sub		cl l	sl.acid	0.85
	Noble County						
3752	Ottie Davis	Billings	surf.	wheat	si l	neutral	0.91
3783			sub		si l	neutral	1.18
3784			surf.	alfalfa	si l	mod.acid	0.88
3785			sub		si cl l	sl.acid	1.10
	Garfield County						
2980	Mrs. Geo. Morrow	Enid	surf.	----	fsl	basic	0.56
	Payne County						
2931	W. R. Sharp	Stillwater	surf.	corn	vfsl	mod.acid	0.70
2932			sub		s cl l	sl. acid	1.80
2937			surf.	virgin	fsl	neutral	2.30
2938			sub	virgin	fsl	neutral	1.18
2939			surf.	wheat	med s	neutral	0.73
2940			sub		fs	neutral	0.67
3779	E. Westfall	Perkins	surf.	wheat	loam	neutral	0.75
3780	Sec 16		sub		si l	sl.acid	0.85
3781			surf.	corn	vfsl	str.acid	0.85
3782			sub		vfsl	str.acid	0.85

Table 6. (Continued) Water-Soluble Boron in Soils from North Central Oklahoma

Lab No.	Land User	Location	Surface or Subsoil	Crop	Soil Class	Soil Reaction	Water Soluble Boron ppm.
	Payne County						
4203			surf.	----	lfs	basic	0.13
4204	Frank Daves	Cushing	sub		lms	basic	0.04
4205			surf.	----	fs	neutral	0.10
4206			sub		vfsl	neutral	0.06
4207			surf.	----	vfsl	sl.basic	0.26
4208			sub		vfsl	basic	0.12

ABBREVIATIONS USED:

lfs	loamy fine sand
lms	loamy medium sand
fs	fine sand
vfsl	very fine sandy loam
s cl l	sandy clay loam
cl l	clay loam
si cl l	silty clay loam
si l	silty loam
fsl	fine sandy loam
med s	medium sand

Central Oklahoma. Central Oklahoma is represented by soils from Oklahoma, Canadian, Hughes and Lincoln Counties, and the results of the analysis of these soils is shown in Table 7. Except for the soils from Hughes and Lincoln Counties, the soils from this part of Oklahoma were somewhat deficient in available boron. In Oklahoma County, except for one soil which came from a garden which probably had been heavily fertilized, the available boron in the surface soils ranged from 0.14 to 0.24 ppm. and that in the subsoils from 0.17 to 0.23ppm. Actually, one cannot say that these soils are deficient in available boron. According to Rogers (27) crops planted on coarse textured soils usually do not have as high a boron requirement as crops planted on finer textured soils. The subsoils in this area had a little more boron than the surface soils, and deeper rooted crops could probably feed on this supply and thus not show a boron deficiency symptom.

Soil samples obtained from Canadian County were also low in available boron. The topsoils ranged from 0.06 to 0.18 ppm. of water-soluble boron and the subsoils from 0.10 to 0.25 ppm.

Table 7 shows that the available boron in the surface soils of Lincoln County was somewhat higher than those of Oklahoma and Canadian Counties. These soils varied from neutral to slightly basic in reaction, which probably accounts for the higher availability in this area. The available boron in these soils ranged from 0.22 to 0.75 ppm. Only one soil had less than 0.70 ppm. The subsoils had somewhat less boron than the surface soils. They ranged from 0.33 to 0.62 ppm. of water-soluble boron.

The soils from Hughes County had more available boron than those from Lincoln County. Only two soils were obtained from this area. These soils were clay soils and may not have been typical of the area. Jordan and Powers (20) are of the opinion that clay soils always have more available boron than coarser textured soils.

Table 7. Water-Soluble Boron In Soilsof C$_e$ntral Oklahoma

Lab No.	Land User	Location	Surface or Subsoil	Crop	Soil Class	Soil Reaction	Water Soluble Boron ppm.
	Oklahoma County						
2981	H.O. Williams	Arcadia	surf.	garden	vfsl	neutral	0.75
2982			surf.	pasture	vfsl	neutral	0.24
4124			surf.	cotton	vfsl	neutral	0.19
4125			sub		vfsl	neutral	0.23
4126	S.M. Hanoe	Monroe	surf.	cotton	loam	sl.acid	0.14
4127			sub		loam	neutral	0.17
4128			surf.	cotton	fsl	sl.acid	0.22
4129			sub		cl l	mod.acid	0.20
	Canadian County						
3002			surf.	rye and	vfsl	sl.acid	0.06
3003			sub	wheat	vfsl	sl.acid	0.10
3004	U.S. Federal	El Reno	surf.	rye and	vfsl	sl.acid	0.08
3004	Reformatory		sub	wheat	vfsl	sl.acid	0.11
3008			surf.	sorghum	loam	sl acid	0.06
3009			sub		s cl l	mod. acid	0.16
3014			surf.	garden	loam	mod. acid	0.18
3014			sub		s cl l	neutral	0!25
	Hughes County						
4450			surf.	----	clay	sl.basic	0.94
4451	T. Bowles	Holdenville	sub		s cl	sl.basic	0.54
4452			surf.	----	clay	s l.basic	0.92
4453			sub		s cl	netral	0.30
	Lincoln County						
4118	James Phipps	Chandler	surf.	corn	fsl	neutral	0.22
4119	SW¼ Sec 21 T 15 R3E		sub		fsl	sl.basic	0.45
4120			surf.	corn	fsl	sl.basic	0.73
4121			sub		fsl	sl.basic	0.62
4122	NE¼ Sec 20 T15 R3E		surf.	corn	fsl	neutral	0.75
4123			sub		fsl	neutral	0.33

ABBREVIATIONSUSED:

cl	clay
v	very
fsl	fine sandy loam
s cl l	sandy clay loam

South Central Oklahoma. South Central Oklahoma is represented by soils from Coal, Johnston, Atoka, Bryan, and Marshall Counties. Table 8 shows the amounts of water-soluble boron that were found in the soils from that area.

The samples from Coal County are representative of three types of soil: upland, bottom, and claypan. They came from an area where hop clover failed to set seed and were brought to the soils laboratory to see if a shortage of boron was the cause. None of these soils seems to be low enough in available boron content to cause a poor growth of the hop clover.

Two soil samples were obtained from Johnston County. Both were topsoils and show quite a contrast. One from a corn experiment had only 0.04 ppm. of water-soluble boron, while the other from a wheat experiment had 0.38 ppm. The one with the low boron content was a fine sandy loam while the other was a silt loam soil. This result agrees with observations made by other investigators on the effect of texture on the amount of available boron in a soil.

The texture of the soils analyzed from Atoka County was a loamy fine sand and the reaction varied from slightly acid to strongly acid. Yet all these soils, as shown by Table 8, are fairly high in available boron, which would seem to contradict the opinions of Berger and Truog (3) and of Rogers (27) who reported that acid and coarse textured soils are usually low in available boron.

The soil samples from Bryan County were clay loam soils and basic in reaction. These soils had from 1.22 to 1.49 ppm. of water-soluble boron in the topsoils, and from 0.65 to 0.94 ppm. in the subsoils. These amounts of boron should be sufficient for most crops.

Table 8. Water-Soluble Boron In Soils From South Central Oklahoma

Lab No.	Land User	Location	Surface or Subsoil	Crop	Soil Class	Soil Reaction	Water Soluble Boron, ppm.
		Coal County					
Official Samples							
11966		Where hop clover failed to reseed 1948	surf.		Upland		field-moist 0.65 air-dry 0.39
11967		Where hop clover failed to reseed 1948	surf.		Bottom		field-moist 0.18 air-dry 0.28
11968		Small pasture east of corral			Clay pan		field-moist 0.39 air-dry 0.47
		Johnston County					
4470	J.L. Smith	Corn Exp.		Corn	fsl	sl.acid	0.04
4471	Mannesville	Wheat Exp.	0"-6"	Wheat	si l	sl.acid	0.38
		Atoka County					
4240			surf.		l fs	str.acid	0.38
4241			sub		l fs	sl.acid	0.36
4242	R.A. Arnold	Lane	sub		fsl	str.acid	0.39
4244			top		l fs	str.acid	0.53
4245			sub		l fs	str.acid	0.63
4246			top		l fs	mod.acid	0.48
4247			sub		l fs	str. acid	0.46
		Bryan County					
2900			surf.	Cotton	cl l	basic	1.49
2901			sub		cl l	basic	0.94
2906	C.L. Decker	Rt #1	surf.	Corn	si cl l	basic	1.42
2907		Kenefic	sub		si cl l	basic	0.65
2911			surf.	Cotton	cl l	basic	1.22
2912			sub		cl l	basic	0.85
		Marshall County					
4155	Frank Vinson	Lebanon	surf.		vfsl	mod.acid	0.17
4156			sub		vfsl	mod.acid	0.22
4157			surf.		vfsl	sl.acid	0.54
4158			sub		vfsl	sl.acid	0.58

Abbreviations used in soil class: fsl--fine sandy loam; si l--silty loam; lfs--loamy fine sand; cl l--clay loam; si cl l--silty clay loam; vfsl--very fine sandy loam.

The soils that were analyzed from Marshall County had from 0.17 to 0.54 ppm. of water-soluble boron in the surface soils and from 0.22 to 0.88 ppm. in the subsoils. The soils were very sandy in texture and somewhat acid in reaction; the soils having the lowest amount of boron were the most acid.

Southwestern Oklahoma. Soils from Southwestern Oklahoma are represented by samples from Cotton, Tillman, and Jackson Counties. The results of analysis of these soils for water-soluble boron are shown in Table 9. Six samples from Cotton County were brought in by R. O. Woodward of the Agricultural Extension Service. Although no information was available concerning the location of these samples in Cotton County, they were used in this study because no other samples from this section were available. The texture of these soils was a sandy loam and they were approximately neutral in reaction. The surface soils contained from 0.14 to 0.26 ppm. of water-soluble boron and the subsoils contained from 0.11 to 0.32 ppm. of boron. There was no significant difference in the quantity of available boron in either the surface of subsoils. All were rather low in boron content for either legumes or cotton.

Tillman County is represented by five top soils, which may or may not be typical for this area. The available boron content ranges from 0.47 to 0.60 ppm. This is higher than that in the soils analyzed from Cotton County and should be sufficient for most crops.

Only four surface soils were analyzed from Jackson County. Three horizons in one soil profile was studied down to 20 inches. This soil had more water-soluble boron in the lower layers than in the surface layer. The soils in the whole group had from 0.10 to 0.25 ppm. of water-soluble boron in the surface soils and that of the subsoils from 0.10 to 0.28 ppm. of boron. One soil had essentially the same amount of boron in both the surface and subsoil, and one less in the subsoil than the surface.

Table 9. Water-Soluble Boron in Soils of Southwestern Oklahoma

Lab No.	Land User	Location	Surface or Subsoil	Crop	Soil Class	Soil Reaction	Water Soluble Boron, ppm.
	Cotton County						
17*			surf.		vfsl	sl.acid	0.26
18	Records on these		sub		vfsl	neutral	0.27
19	soils cannot be		surf.		vfsl	neutral	0.14
20	found.		sub		fsl	neutral	0.11
21			surf.		vfsl	sl.basic	0.27
22			sub		fsl	neutral	0.32
	Tillman County						
2966			surf.	Wheat	vfsl	basic	0.54
2967	Clarence Meece	Frederick	surf.	Wheat	vfsl	basic	0.73
2968			surf.	Wheat	vfsl	basic	0.59
2969			surf.	Sw.Cl.	vfsl	neutral	0.60
2970			surf.	Sw.Cl.	vfsl	neutral	0.47
	Jackson County						
3057			surf.		fsl	sl.acid	0.25
3058			sub		fsl	sl.acid	0.24
3059	Lee Bond	Altus	surf.		fsl	mod.acid	0.23
3060			sub		fsl	sl.acid	0.10
3061			0"-6"		fsl	mod.acid	0.10
3062			6"-12"		fsl	neutral	0.28
3063			12"-20"		fsl	sl.acid	0.22

*These samples were not part of regular laboratory sa ple. They were brought in for this study by Mr. R.O. Woodward.

ABBREVIATIONS USED IN SOIL CLASS:

vfsl--very fine sandy loam
fsl--fine sandy loam

Western Oklahoma. The western part of Oklahoma and the Panhandle area was represented by soil samples from Dewey, Beckham, Washita, Kiowa, Greer, and Texas counties. Table 10 contains information concerning the amounts of water-soluble boron that were found in the soils from this area. The quantity of available boron in the surface soils ranged from 0.12 to 2.28 ppm., with the highest amounts found in soils from Kiowa County, and the lowest from Dewey County. The amount found in the subsoils ranged from 0.12 to 2.04 ppm., with the highest found in soils from Kiowa County, and the lowest from Beckham County. Only one group of soils was secured from the panhandle area, and they are probably fairly representative of the area. These soils were of the Richfield silt loam type and were basic in reaction. According to a letter received by the author from George L. Roberts, the vocational agricultural instructor at the Hardesty High School, up to five inches of top soil has been lost from this area due to dust storms. The top soils had from 0.44 to 0.76 ppm. of available boron and the subsoils from 0.37 to 0.94 ppm. The fine texture of the soils from this area would be favorable for a high available boron content, but the basic nature of the soil may have had a depressing effect on the solubility. Also loss of surface soil by erosion would tend to reduce the amount of available boron now present in the surface layer.

Table 10. Water-Soluble Boron In Soils From Western Oklahoma and The Panhandle Area

Lab No.	Land User	Location	Surface or Subsoil	Crop	Soil Class	Soil Reaction	Water Soluble Boron, ppm.
	Dewey County						
4269	F.M. Hedges	Seiling	surf.	Wheat	loam	sl.basic	0.60
4270	NW¼ Sec 3 T13, R16		sub		fsl	sl.basic	0.42
23			surf.		fsl	basic	0.14
24			sub		fsl	basic	0.31
25			surf.		fsl	sl.basic	0.22
26	Records for these		surf.		fsl	basic	0.36
27	soils were not		sub		fsl	basic	0.30
28	available.		surf.		fsl	basic	0.12
29			surf.		fsl	basic	0.26
30			surf.		fsl	Neutral	0.09
31			surf.		fsl	basic	0.26
32			surf.		fsl	Neutral	0.14
33			surf.		fsl	sl.basic	0.20
34			surf.		fsl	basic	0.22
35			surf.		fsl	sl.basic	0.23
36			surf.		fsl	sl.basic	0.24
	Beckham County						
3748	O.R. Dowdell	Elk City	surf.	Alfalfa	fsl	neutral	0.58
3749			surf.	Alfalfa	fsl	neutral	0.72
3750	(irrigated)		surf.	Corn & Veg	fsl	neutral	1.30
3751			surf.	Corn&Grain	fsl	neutral	1.28
3773	R.E. Gipson	Texola	surf.	Alfalfa	fsl	basic	0.54
3774			sub		lt fs	sl.basic	0.42
3775			surf.	Alfalfa	fsl	basic	0.44
3776			sub		lt fs	basic	0.36
4121	Grant Golden	Elk City	surf.		lfs	basic	0.18
4142			12"-18"		lfs	basic	0.39
4143			18"-20"		lfs	basic	0.16
4144			surf.		lfs	basic	0.48
4145			12"-18"		lfs	basic	0.12
4146			18"-20"		lfs	basic	0.12
	Washita County						
3761	Philip Delo	Foss	0"-8"		fsl	basic	0.70
3762			8"-20"		fsl	basic	0.64
3763			15"-20"		fsl	Basic	0.70

Table 10. Water-Soluble Boron in the Soils From Western Oklahoma and the Panhandle Area (Continued)

Lab No.	Land User	Location	Surface or Subsoil	Crop	Soil Class	Soil Reaction	Water Soluble Boron, ppm.
		Kiowa County					
4486			surf.	Cotton	si l	sl.basic	2.24
4487	F.R. Smith	Gotebo	sub		si l	sl.basic	1.44
4488			surf.	Cotton	si l	sl.basic	0.80
4489			sub		cl l	basic	2.04
4490			surf.	Cotton	si l	basic	2,28
4491			sub		cl l	basic	1.88
		Greer County					
2919			0"-6"	Cotton	si cl l	basic	1.33
2920	E.C. Johnson	NW¼ Sec 30	6"-12"	Wheat	si cl l	basic	1.21
2921		T7W R23	0"-10"	and	si cl l	basic	0.93
2922			10" +	Grain	si cl l	basic	0.95
		Texas County					
3738			surf.	Wheat		basic	0.44
3739	Hardesty High	Hardesty	sub			basic	0.37
3740	School	SE¼ Sec 28	surf.	Wheat		basic	0.74
3741		T2 R18	sub			basic	0.84
3742			surf.	Wheat	silt	basic	0.68
3743			sub			basic	0.94
3744			surf.	Wheat		basic	0.76
3745			sub		loam	basic	0.64

ABBREVIATIONS USED IN SOIL CLASS:

si l	silty loam
si cl l	silty clay loam
cl l	clay loam

BORON CONTENT OF CROPPED AND VIRGIN SOILS

It was only possible to obtain virgin soils from two areas, Craig County and Payne County. Therefore, it would be impossible to state just how virgin and cropped soils compare in any of the other areas in regard to boron content. Data for the virgin soils which came from Craig County are shown in Table 4. They do not differ very much in boron content from the cropped soils, with the exception of the Summit clay, a native pasture, which contained 0.36 ppm. of water-soluble boron in the surface soil and 0.75 ppm. in the subsoil in comparison to about 0.15 ppm. in the top soil and 0.05 in the subsoil of the cropped land. It would seem that this virgin soil probably has more organic matter than the other virgin soils, and this may be the reason for the higher boron content.

One virgin and cropped comparison was obtained from Payne County, and the data are shown by Numbers 2937 and 2938 in Table 6. The virgin sample had 2.30 ppm. of water-soluble boron in the top soil and 1.18 ppm. in the subsoil, and contained from three to twenty times as much available boron as the soil from the cropped land. It is probable that part of the reason for this was that the virgin soil was neutral whereas, the cropped land was somewhat acid in reaction. It is also possible that some boron has been lost from the cropped soil due to erosion.

It is rather difficult to make a comparison between soils in regard to the amount of available boron they contain. As was pointed out by Berger and Truog (3), increasing acidity or alkalinity decreases the amount of available boron in a soil. They also stated that the amount of organic matter, which tends to keep the boron available, has a great deal to do with the amount that will be available in any soil. Thus it can be seen, that when one starts to compare soils for available boron content, both physical and chemical variations between the samples must be considered.

A COMPARISON OF TOTAL AND WATER-SOLUBLE BORON IN SOIL

In view of the fact that sufficient time was not available to analyze all the soils for total boron, a few samples which had a high content of water-soluble boron and a few that were low in water-soluble boron were selected for this study.

Table 11 shows the results of analysis for total boron. Also shown for comparison are the amounts of water-soluble boron that were found in these soils and the ratio between the two.

Table 11. A Comparison of Total and Water-Soluble Boron in Soils

Sample No.	surf. or subsoil	Water-Soluble Boron ppm.	Total Boron ppm.	Ratio of Total to Water-Soluble Boron
5	surf.	0.10	1.03	10.3
6	sub	0.05	0.30	6.0
7	surf.	0.19	1.51	8.0
8	sub	0.02	0.50	25.0
4203	surf.	0.13	5.00	38.5
4204	sub	0.04	5.00	125.0
4205	surf.	0.10	20.00	200.0
4206	sub	0.06	25.00	416.0
4141	surf.	0.18	25.00	139.0
4142	12"-18"	0.39	10.00	25.5
4143	18"-20"	0.16	10.80	67.9
4486	surf.	2.24	25.00	11.9
4487	sub	1.44	20.00	14.0
4488	surf.	0.80	17.00	21.3
4489	sub	2.04	20.50	10.0
4490	surf.	2.28	10.25	4.5
4491	sub	1.88	12.00	6.4

The data presented in Table 11 show that soils low in available boron are not always low in total boron. Sample number 4206 had only 0.06 ppm. of available boron, but the total boron content was 25 ppm. Soil number 4486 with 2.24 ppm. of available boron contained 25 ppm. of total boron.

Sample number 4490 had 2.28 ppm. of water-soluble boron, but only 10.25 ppm. of total boron. These results show that soils with a high amount of available boron may not have as much total boron as a soil that is lower in available boron content. The ratios between water-soluble and total boron varied from less than 1 to 5 to more than 1 to 400. These findings are in agreement with those of DeTurk and Olson (13) in relation to total and available boron in soils.

EFFECT OF SUCCESSIVE REFLUXING OF SOIL WITH WATER ON THE BORON CONTENT OF THE SOIL EXTRACTS

It is known that successive extractions of a soil with a dilute solvent will continue to liberate a considerable quantity of phosphorous and potash. Since boron compounds in soil may behave in a similar manner when treated with water, four soils that were high in available boron were each refluxed three successive times, allowed to stand about a week and then refluxed again. These results are shown in Table 12, and the data from the first three refluxings are shown graphically in Figure 2.

Table 12. Effect of Successive Refluxing of Soil on Boron Content

Sample No.	First Reflux (ppm) Boron	Second Reflux (ppm) Boron	Third Reflux (ppm) Boron	After One Week (ppm) Boron
4486	2.28	2.02	1.92	0.30
4487	1.48	1.30	1.20	0.36
4490	2.20	1.10	0.94	0.10
4491	1.94	1.70	1.62	0.44

Because the amount of boron removed after the soils stood for a week was out of proportion to that removed previously, the figures were not plotted on the graph shown in Figure 2. An examination of both Table 12 and Figure 2 shows that water-soluble boron does not follow the same pattern obtained when phosphorus and potash are extracted with dilute solutions. Progressively less boron was released in each successive refluxing. In the case of sample Number 4490, a sudden drop occurred in the amount of boron removed after the second refluxing. This shows that the boron in the inactive fraction was not released as it was in the other samples. Olson and Berger (24) have pictured available boron as being released from inactive forms as fast as it is removed. The findings for this one soil do not support such an assumption.

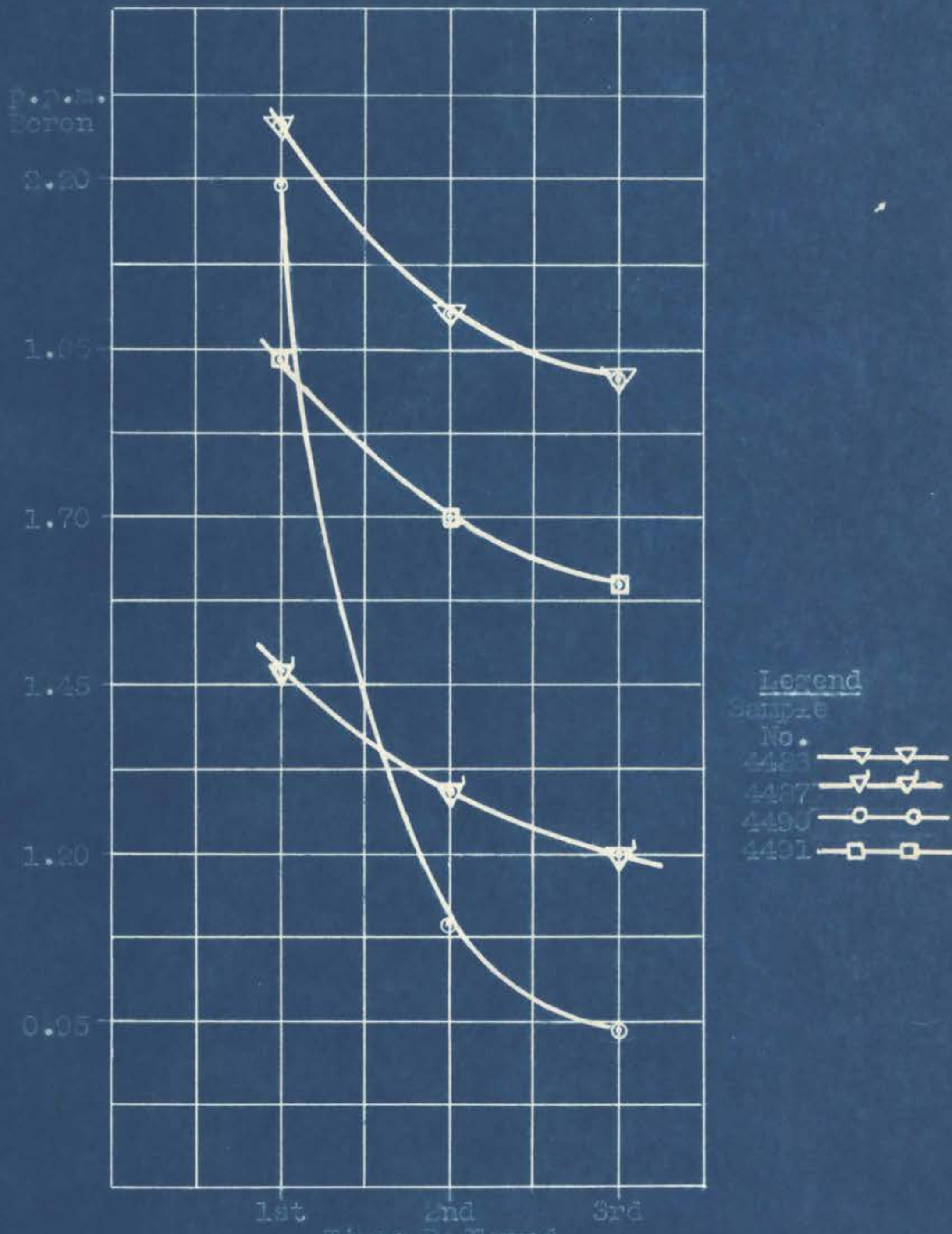

Figure 2. Effect of Successive Refluxing
Of Soil On Boron Content

The results obtained in this experiment would indicate that one refluxing of a soil does not tell the whole story, and that perhaps it would be better to reflux a sample more than once to determine the ability of a soil to continue to supply boron for plant growth, especially on soils of low available boron content.

RELATION BETWEEN QUANTITY OF WATER-SOLUBLE BORON IN SOIL AND CROP RESPONSE TO BORON FERTILIZATION

Very little data has been published on how much available boron a soil should contain to produce a good growth of different crops. The literature that could be found on this subject indicates that crops are quite variable in their boron requirements.

In Table 13 are shown the amounts of available boron that are needed for the crops listed and the sources of information.

Table 13. Amounts of Available Boron In Soils Needed For Optimum Growth Of Crop

Crop	Amount of Boron Needed In Soil, ppm.	Source of Information
Alfalfa	0.35	Schaller (28)
Alfalfa	0.15	Rogers (27)
Alsike Clover	0.50	DeTurk and Olson (13)
Bountiful Beans	0.50-0.75	Jordan and Powers (20)
Citrus Trees	less than 0.5	Derby (12)
Cotton	10.00 (in sand)	Eaton (14)
Crimson Clover	0.30	Naftel (24)
Lespedeza	0.50	DeTurk and Olson (13)
Red Clover	0.50	DeTurk and Olson (13)
Red Clover	1.00	Gilbert and Pember (15)
Soybeans	None	Collings (8)
Soybeans	Trace	Rogers (26)
Sugar Beets	1.00	Berger and Truog (4)
Tomatoes	0.55	Johnston and Dore (18)

The author realizes that the number of crops shown in Table 13 is small, but information on this subject appears to be quite limited.

Using the above table as a base on which to predict crop response for the different areas of Oklahoma it would seem that a few sections of the state are not capable of producing high yields of the crops listed. If any of these crops are grown on soils which do not contain as much available boron as is required for those crops, it would be expected to find symptoms of deficiency, lowered crop yields, or as the case with some legumes, failure to produce seed.

The soils that were analyzed from Craig County show a boron content that is considerably below most of the requirements for the crops listed in Table 13, with the exception of soybeans. Nothing definite was found in the literature as to the boron requirements of corn, small grains, or the grasses, but what has been stated as to the amounts that are needed in the plants themselves, leads to the conclusion that the requirements for these crops are considerably below that of leguminous plants. Eaton (15) states that corn, barley and oats need from 1 to 5 ppm. of boron in the plants for healthy growth, whereas alfalfa and most of the other legumes, with the exception of soybeans, require 10 ppm. in the plants. Cook (10) could get no response in barley and corn by the additions of small amounts of boron as borax to the nutrient medium when growing these plants in sand cultures, and concluded that the requirements of these plants were so small that they were able to grow well on the small amount of boron that was stored in the seed, or else obtained it from the sand. It can, therefore, be assumed that small grain does not need much available boron in the soil, and it is possible that soils low in boron content for legumes may produce fairly good yields of grain crops.

This information can also be applied to other sections of the state where the soils are low in available boron, with the exception of soils that are basic in reaction. In these soils, one must consider the fact that when the soil reaction is alkaline, boron is not released from the fixed state as fast as when the soil is approximately neutral in reaction (3). In view of this fact, where legumes are grown for soil building purposes or for forage, and the available boron content of the soil is near the lower limit for good growth in legumes, it might be well to apply fertilizers containing boron where the soils are basic in reaction.

There seems to be a scarcity of actual recommendations for boron fertilization for the various crop plants. A few workers in scattered sections of the country have attempted to make recommendations for some crops that have shown boron deficiency symptoms in certain areas. Jordan and Powers (20) stated that twenty to forty pounds of borax per acre applied broadcast controls "yellow top" on the medium textured soils of Oregon, but that an application of 60 pounds per acre will increase the yield when the boron supply in the soil is below the required amount.

Rogers (26) reported that a single application of 20 pounds of borax per acre produced maximum yields of alfalfa for three years on sandy soil low in native boron in Alabama.

Ahlgren (2) stated that boron deficiency in alfalfa may be corrected by the addition of 10 pounds of borax per acre on light soils and 20 pounds per acre on the heavier soils of New Jersey. On the other hand, Colwell and Baker (9) reported that 40 to 60 pounds of borax per acre seemed best for good growth of alfalfa in northern Idaho, but they did not state the type of soil which was studied.

An examination of Table 13 shows that the boron requirements of most of the legumes are essentially the same, and in view of this fact, one could probably say the recommendations for boron fertilization for one legume would also apply to other legumes, except for soybeans. Some workers have reported how much borax produces the best results for a few of the legumes, but their reports are for sand cultures and would have to be revised for soils. Cook (10) has reported that alsike clover grew well in sand when supplied with borax at the rate of 3 pounds per acre and alfalfa needed 2 pounds per acre when grown in sand. On the basis of

Jordan and Powers (20) recommendation of 60 pounds of borax per acre for alfalfa, this would mean that alsike clover would need 90 pounds of borax per acre when grown on medium textured soil. This seems logical as is shown in Table 13, alsike clover needs 0.50 ppm. available boron in the soil (13), but alfalfa only needs 0.35 ppm. of boron (28).

Not very much work has been done on the problem of the boron needs of other crops so far as actual recommendations for boron fertilization is concerned. Cook (10) has worked with sugar beets in Michigan, and states that as much as 80 pounds of borax per acre may be used without any detrimental results. Coleman (7) reported that 20 pounds of borax per acre may be applied to Grenada silt loam for cotton, and that this amount has resulted in an increase of 125 pounds of seed cotton per acre over plots not fertilized with boron.

It would seem, because of Coleman's (7) report, that many of the areas in the southern part of Oklahoma, where cotton is grown, would benefit greatly by the use of boron-containing fertilizers. Most of the soils analyzed for available boron where cotton was the reported crop had sufficient boron to satisfy the immediate crop needs for boron, but these soils were all basic in reaction and may become deficient in available boron as the season progresses, because the boron in the soil may not be released as fast as the plants need it.

In the western part of Oklahoma, where the main crop is wheat, the soils seem to be well supplied with available boron for this crop, since the boron requirement of wheat is quite low, as was stated previously in this paper.

Although this investigation has shown that the majority of the soils in Oklahoma are apparently well supplied with available boron, a few scattered areas are in need of boron fertilization. Most of these areas are located on the sandier soils in the central and eastern sections of the state, and possibly in some of the southern sections where the soils are basic in reaction and where cotton, with a high boron requirement, is grown.

DISCUSSION

This investigation concerning the boron content of Oklahoma soils has shown that boron deficient soils are not necessarily located in any one area, although the majority of the samples low in boron content came from the central and eastern sections of the state. It is also apparent, from a review of the literature on the needs of certain crops for boron, that all crops are not alike on the amounts of available boron needed to make a good growth. Furthermore, all crops have not been investigated as to how much borax should be applied to overcome a boron deficiency. In view of these facts, one would hesitate to say that a certain soil is deficient in available boron even though an analysis shows that soil contains less water-soluble boron than another.

After reviewing the literature on recommendations for boron fertilization for certain crops, it seems that a recommendation for a certain area may not apply in another area due to differences in soil texture or soil reaction. Analysis of soils to determine where areas low in available boron are located is necessary to find out where deficiency symptoms in plants are likely to develop. In view of the foregoing statement as to the differences in boron needs of a crop grown in various sections of the country, it is apparent that field experiments should be conducted in areas that are low in available boron using the crops that are usually grown in those areas. Until this is done, it cannot be definitely stated which soils are deficient in available boron content.

SUMMARY

A study was made of the water-soluble and total boron in Oklahoma soils.

Analytical methods for determining water-soluble and total boron in soils were studied and the methods described.

One hundred and sixty nine soil samples coming from 28 counties, and representing a fairly good cross section of the state, were used in this study.

The results of the analyses indicate that the majority of the soils tested are well supplied with boron for the crops grown.

The number of soils as to content of boron were: 8 below 0.10 ppm.; 52, 0.10 to 0.30 ppm.; 23, 0.30 to 0.50 ppm.; 62, 0.50 to 1.00 ppm.; and 24 had over 1 ppm.

Soils deficient in available boron are scattered throughout the state, but a majority was found in the eastern and central areas.

The soils containing less than 0.30 ppm. of available boron would be considered deficient for legumes, but probably enough for grains and grasses. Soils containing more than 0.30 ppm. usually have sufficient boron for most crop needs.

It is apparent, from a comparison of a few virgin and cropped soils, that the virgin soils usually contain more available boron than cropped soils.

Successive refluxing of soils with water was found to remove progressively less water-soluble boron with each successive refluxing, and it was concluded that this might be a better index of a soil's ability to supply a continuous quantity of available boron to plants than a single treatment.

The amounts of available boron in soils that are needed for a good growth of some crops are listed, and a discussion was made as to the amounts of borax that will overcome soil deficiencies for different crops.

More field experiments on soils low in available boron are needed to determine the amounts of borax which should be applied to overcome these deficiencies for different crops.

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APPENDIX

Boron in Fertilizers

A test was made for water-soluble boron in four fertilizer materials that are commonly used in fertilizer mixtures. Data on the available boron in Ammonium Sulfate, Chilean Sodium Nitrate, 16% Superphosphate, and Muriate of Potash are given in Table 14.

Table 14. Water-Soluble Boron in Fertilizer Materials

Material	Water-Soluble Boron ppm.
Ammonium Sulfate	0.145
Sodium Nitrate	0.18
Superphosphate	0.27
Muriate of Potash	0.10

It had been expected that muriate of potash would contain the most boron, but as seen in the above table, it was the lowest of the materials tested.

It can readily be seen that none of these fertilizer materials would furnish sufficient boron to meet plant requirements. This is the reason why some soils, low in available boron, do not produce good yields even though the principal plant nutrients have been furnished in the desired quantities, unless some borax is added to the fertilizer mixture applied to the soil.

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