OPTIMUM AND CRITICAL CONCENTRATIONS OF BORON IN OREGON SOILS

by

JAMES VERDUN JORDAN

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APPROVED:

[redacted]

Head of Department of Soils

In Charge of Major

[redacted]

Chairman of School Graduate Committee

[redacted]

Dean of Graduate School

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TABLE OF CONTENTS

FIGURES

OPTIMUM AND CRITICAL CONCENTRATIONS OF BORON IN OREGON SOILS

INTRODUCTION

The need of boron as a fertilizer constituent for certain Oregon soils was indicated two decades ago during plant-house experiments. Its economic value in improving yields and quality of alfalfa, beets, celery and other crops in the state was established approximately ten years ago. Boron deficiency in Oregon soils has developed in the more humid areas of the state, notably in the lighter textured soils lying west of the Cascade Range. This area is subject to heavy rainfall and leaching. Boron deficiency in these soils has been further aggravated by the use of modern commercial fertilizers, relatively free from impurities which previously contained small amounts of boron. Increasing mechanization of farming methods has also been responsible for reducing an important source of boron fertilization by natural manures.

Abnormal accumulations of boron have developed locally in those alkaline soil areas of Eastern Oregon. These soils are not subject to leaching and the boron is present with the unleached salts. Low lying recent soils with poor drainage as typified by Klamath peat and soils of the Silvies Valley have been subjected to seasonal flooding for generations which has resulted in alkali and boron accumulation.

The object of this investigation was to establish an approximate optimum range of concentration for available boron in Oregon soils and to prepare an availability map for the state showing the low, optimum and high available boron zones. During the course of this study the soils and plant material were utilized to determine the effect of soil type on germination at different concentrations of boron and to determine the effect of boron on nitrogen content of plants.

FORMS OF BORON IN SOILS. Although boron is rarely found to occur naturally in soils in sufficient quantity to injure even sensitive plants, it is believed to be present in some concentration in all soils. Much of the total boron of soils occurs in the form of borosilicates and other resistant boron minerals, such as tourmaline, that have been transported and laid down during soil formation. In addition, boron often occurs in the soil as an impurity in other relatively insoluble minerals (Schaller, 1929). Soluble sources of boron are sodium tetraborate, $Na_2B_4O_7$; borax, $Na_2O \cdot 2B_2O_3 \cdot 10H_2O$; boric acid, H_3BO_3; calcium borate; kernite, $Na_2O \cdot 2B_2O_3 \cdot 4H_2O$; colemanite, $2CaO \cdot 3B_2O_3 \cdot 5H_2O$ and ulexite, $Na_2O \cdot 2CaO \cdot 5B_2O_3 \cdot 16H_2O$.

According to Hasler (1942), Jurassic marl and marly clay have the greatest content of water soluble and available boron. Eruptive and metamorphic rocks cannot be used as sources of boron for plants.

Berger and Truog (1940) divide the boron present in soils into three categories, namely total boron, acid-soluble boron and water-soluble boron. Their analyses show that the total boron content of a soil is not a reliable indicator of the need for boron fertilization, because, generally, less than 5 per cent of the total boron is in available form. The unavailable, or better, difficultly available, form is often present as tourmaline.

MAPPING BORON AVAILABILITY. The recent increase in interest in the distribution of nutritional troubles in plants is a natural sequence to earlier work of diagnosing and classifying these defects and their various symptoms. Investigators are interested now in more than a mere description of the disorders observed and frequently wish to visualize the geographic extent of nutritional problems. This is best accomplished by reference to a map.

Exploratory field trials and several hundred laboratory determinations of boron in Oregon soils and in the various parts of indicator plants grown thereon have developed information as to boron needs of Oregon soils. A preliminary availability map of the state has been prepared.

MICROBIOLOGICAL RELATIONSHIP OF BORON. The study of the functional effects of boron in the nutrition of micro-organisms appears to rest in a stage similar to that period before Agulhon (1910) found boron to be an essential nutrient of higher plants. Boseken and Waterman (1912) report that the depressing influence on the growth of Penicillium glaucum and Aspergillus niger depended in part on the nature of the nutritive medium. At 21°C. pure cultures of Penicillium glaucum grown from conidia were clearly depressed by 0.06% boric acid, while under like conditions, 0.5 - 1% boric acid was required to check the development of Aspergillus niger. Brenchley and Thornton (1925) and Dufrenoy (1940) report that boron is essential to the development of vascular strands in root nodules of Vicia faba so that normal nitrogen fixation is contingent on an adequate boron supply. Lebedev (1940) found that boron stimulated development of the lupin nodules and aided the growth of hemp when grown with lupins.

Evidence that borax increased microbiological activity at pH 5.1-7.7 was demonstrated by Hanna and Purvis (1941) who measured carbon dioxide evolution. Their plate counts showed a greater stimulation of fungi growth over that of bacteria. They suggest the *Trichoderma* species may be of value as a test for boron deficiency and that the fixation of boron in limed soils may be due in part to the increased activity of soil microorganisms. Tyner (1944) reports a similar stimulation of fungi and suppression of bacteria in using boric acid treatments when using potato dextrose agar or synthetic media.

Herzinger (1940) reported the growth of *Azotobacter chroococcum* in soil and culture solution at pH 6.8 to be noticeably better at a concentration of 0.00001 M boric acid and reached an optimum at 0.000005 M boric acid.

BORON IN ANIMAL NUTRITION. The relatively few publications on this subject indicate that boron is present in animal tissue but does not appear to be an essential nutrient for normal life. Bertrand and Agulhon (1912) and (1913) report finding small amounts of boron in the hair, bones, horn, liver and muscles of 27 species of animals but was more common in species of marine origin. In a further paper the same authors (1913) report finding 0.08, 0.1 and 0.2 milligrams of boron per litre in the milk of humans, asses and cows. Fowl, turkey and goose eggs contained 1 milligram per kilogram of dried material. Bertrand (1938) states that boron exists in very small quantities in all plants and animals and the amount present in plants is 100 to 200 times greater than in animals. Hove and co-workers (1939) at Wisconsin found no significant difference in boron content of milk between cows of different breeds nor for different periods of the lactation cycle.

They report it is possible to increase the boron concentration of the milk tenfold in the first 24 hours after feeding 13 grams of boric acid. Normal egg white contains 8 to 10 times more boron than egg yolk, and this ratio is not altered significantly when the fowls are fed a high boron diet. The same investigators found that boric acid fed to rats is eliminated rapidly and the addition of 0.8 micrograms of boron per day per rat does not result in better growth. The studies of Orent-Keiles (1940) corroborated the conclusion of Hove and associates that boron is not essential in the nutrition of the rat. Teresi, Hove and associates (1944) further report that rats receiving a ration containing 0.6 micrograms per day satisfied their requirements while 155 micrograms per kilogram of basal ration did not improve the ability of rats to nurse their young. Owen (1944), investigating the effects of a high boron ration for feeding dairy cows reported there was no diuretic effect, loss of weight or any other ill effect. However, he suggests there may be a risk to subsequent plant growth from the use of manure from animals fed too much borax.

HISTORICAL

EARLY WORK. Boron was found to be a constituent of plant tissue by Wittstein and Apoiger (1857) who found boric acid in the seed of Maesa picta. The importance of this discovery was not apparent until years later when Baumert (1888) detected boron in wines, and Crampton (1889) and Callison (1890) found boron in various fruits and predicted that the occurrence of boron in the plant kingdom would be far more general than previously supposed. This prediction received further support when Hotter (1890) found boron not only in the fruits of many species but also in the leaves and tissues of a great variety of plants. Jay (1895) finally suggested that boron might be universally distributed throughout the plant kingdom.

Bertrand (1903) recommended the use of boron in commercial fertilizers. Agulhon (1910) found that applications of boron increased the dry weight of plants. Perhaps the outstanding publications of this period were those of Bertrand (1912) and Maze (1914), who discovered the essential nature of boron in plant life.

Cook (1916) discovered the toxic effects to larvae, of boron added to manures. He noted the beneficial effects of the element when applied to peach trees, and obtained large increases in the yield of potatoes. The toxic effects of boron received attention during World War I, when substitutes for German potash were used. Connor and Fergus (1920) found that potash derived from western salines contained sufficient boron to be toxic when applied to crops.

ESSENTIAL NATURE OF BORON. Brenchley and Warrington (1921) reported that various legumes could not be grown to maturity in the absence of boron. This element was found to be essential for the translocation of nutrients throughout plant tissue by Johnson and Dore (1928), which function was substantiated by Dennis and O'Brien (1937).

Schmucker (1935) discovered that boron played an essential role in pollenation, by preventing excessive swelling and bursting of pollen tubes. He further suggested that it may play some part in the formation of pectin. Hughes and McLean (1936) recognized that boron lessened the effects of drouth and served to improve the keeping quality of fruit, since it controlled respiration. Powers (1939) reported that boron applications to the soil increased the boron content and longevity of alfalfa. Plants adequately supplied with boron had a higher protein, chlorophyl and vitamin A content than boron deficient plants.

Eaton (1940) reported boron to be essential in the production of auxins. This author (1944) studied the sensitivity of 72 crops to boron and divided them into 3 groups: tolerant, semi-tolerant and intolerant to boron.

BORON RELATIONSHIP IN PLANTS. In recent years, investigators have been studying the relationship between boron and plant nutrient assimilation and plant composition. Warrington (1934) found evidence of a boron and calcium association. Foote and McElhiney (1937) working with lemon trees reported that available nitrogen present as nitrate in the soil influences rate of boron intake in lemon leaves. When nitrate is deficient, boron accumulates in the leaves faster than if growth is not retarded by a nitrate deficiency. Drake et al (1941) studying tobacco growth on Indiana soils reported normal growth when calcium/boron ratio in the plants did not exceed 1340: 1, while a ratio 1500: 1 was correlated with severe boron starvation. Lorenz (1941) in his study of garden beets reports that boron was more efficient in increasing growth at low than at high levels of Ca supply and boron appeared to improve utilization rather than absorption of calcium. Lowenhaupt (1942) studying the nutritional effects of boron on the growth of sunflowers found that boron-deficient plants contained less calcium than normal plants, supporting the hypothesis that boron regulates the nutrient translocation throughout the plant. Scharrer and Schreiber (1942) working with corn growing in sand cultures report that the addition of boron alone had little effect on yield but the absorption of magnesium is enhanced by the presence of boron. Potassium-boron relationship in plants was studied by Keene and Shive (1943) using sand cultures. They found that the rate of boron absorption by both corn and tomato plants increases as the concentration of potassium in the substrate is increased. The same authors (1944) report that boron toxicity at high boron levels decreases markedly as the calcium concentration increases. In this respect they found the influence of calcium to be opposite the accentuating effect of potassium. Haddock and Vandecaveye (1945) report that under their experimental conditions with alfalfa, critical potassium/boron and calcium/boron ratios were above 50 and 180 respectively.

ECONOMIC IMPORTANCE OF BORON. The economic importance of boron was investigated and calculated for alfalfa by Powers (1939) and Dregne and Powers (1942);

beets by Powers and Bouquet (1941) and celery by Bouquet and Powers (1939). Canneries reported that the daily pack beets was increased 75 per cent due to the lessened blackening of the roots and the reduced handling of infected beets. Powers (1947) has estimated that if boron was supplied to the present acreage of six responsive crops from lower Hood River Valley to Coos Bay, crop value would be increased by over one million dollars.

Since maximum economic returns are dependent in the case of boron, on the narrow optimum range of available soil boron it is desirable to determine a fairly accurate range between the low and high critical concentrations.

EXPERIMENTAL

The problem was studied through the media of greenhouse and field experiments. The principal indicator plant for the greenhouse trials was the Bountiful bean, chosen because of its rapid growth and semi-tolerance toward boron. Sweet corn and tomatoes comprise the field crops.

The effect of soil boron content on the nitrogen assimilation by the plant is included and also its effect on seed germination in soils of varied textures.

The second part of the problem, a soil boron-availability map of the state, is presented. This map is not complete but covers the available boron status of Oregon soils in a general manner so as to permit zoning agricultural areas into low, optimum and high boron supply.

DESCRIPTION OF SOILS. The soils used in the field and greenhouse trials were Chehalis, Melbourne, Newberg, Camas and Klamath peat.

The Chehalis series is a recent alluvial soil representing a second-bottom soil laid down in backwater as from the Willamette River and has a less youthful profile with heavier subsoil. The color is brown on finer, mellow yellow-brown subsoil. The pH is 6.1 and the base exchange capacity is 14.7 milliequivalents per 100 grams.

The Melbourne series is a residual soil derived from sedimentary rocks. The color is brown on a yellowish mottled subsoil. Surface drainage is good and internal drainage fair. The pH is about 6.0 and the base exchange capacity, 28.3 milliequivalents per 100 grams.

The Newberg series is a recent alluvial soil and has a brown surface and yellow-brown subsoil with a friable profile. It is a first-bottom soil laid down in swift water, giving it coarser subsoil. The reaction is pH 6.0 and the base exchange capacity is 13.7 milliequivalents per 100 grams.

The Camas series is a recent alluvial soil with a gravelly subsoil. The color is a brown surface on a lighter brown subsoil. Drainage is good. Reaction is about pH 6.0 and the base exchange capacity 12.2 milliequivalents per 100 grams.

The Klamath peat has a dark gray to black surface and a light gray subsoil. It contains fresh water shells and is high in salt content. The pH of the soil used is 9.5 and the base exchange capacity, 75 milliequivalents per 100 grams.

ANALYTICAL PROCEDURES. Plant samples were dried at 60°C. and were ground in a Wiley mill to pass a 100-mesh sieve, after which representative portions were taken for analysis.

Soil samples were air-dried and clods and gravel removed by screening through a 20-mesh sieve.

Plant material was analysed for total boron, and soil samples for available boron by the colorimetric method of Berger and Truog (1940), using quinalizarin as the color developer. The color developed in the solution from the samples was compared with color standards. In this procedure, the addition of boric acid to quinalizarin (1, 2, 5, 8-tetrahydroxyanthroquinone) in concentrated sulfuric acid causes a color change which can be used for the determination of boron.

Soil reaction was measured with a standardized Beckman pH meter using 50 gram samples moistened uniformly to moisture capacity.

Base exchange capacities of the five soil types were determined using the modified Parker Method (Wright, 1939). In this procedure the soils are leached with barium chloride, the excess being removed with neutral ethanol. The barium is then replaced with the ammonium ion by leaching with ammonium acetate. Barium from the exchange complex is determined gravimetrically as barium sulfate.

FIELD EXPERIMENTS. The field experiments were conducted on Chehalis silty clay loam at the Horticulture

Farm where plots were made available by the Soils Department. Tomatoes and sweet corn were seeded in the spring of 1945, fertilized with borax and harvested in September. The rates of borax varied from 0-320 pounds per acre and 3 methods of application were used, namely broadcast, side-drill and spray.

In order to determine the optimum and critical concentrations of boron in Chehalis silty clay loam, the available boron in the soil under the different treatments was determined. Boron analyses of the different plant parts were conducted to establish which part of the plant would serve best as a criterion for determining toxicity or deficiency. The plant parts here are stems, fruit and first mature leaf.

TABLE I. The data indicates that Chehalis silty clay loam at the Horticulture Farm is normally deficient in available boron insofar as the growth of tomatoes and sweet corn are concerned. The low critical concentration is 0.5 ppm. Yields attain a maximum of 133 pounds of tomatoes and 96 pounds of sweet corn per square rod at 0.85 ppm. and 0.80 ppm. available boron respectively. Available boron values above 0.85 ppm. gave somewhat depressed yields which, however, exceeded yields from the check plots.

TABLE I. OPTIMUM AND CRITICAL BORON CONCENTRATIONS IN CHEHALIS SILTY CLAY LOAM

Tomatoes and Sweet Corn

CROP	BORAX APPLICATION		AVAIL. SOIL B.	BORON IN PLANT PARTS			YIELDS	FRUITS CRACKED BY RAIN
	METHOD	RATE	9-22-46	STEMS	LEAVES	FRUITS		
		lb/acre	ppm.	ppm.	ppm.	ppm.	lb/sq.rod	per cent
Tomatoes	broadcast	40	0.40	30	80	10	59.8	45.9
	"	80	0.50	35	80	10	69.4	32.2
	"	160	0.80	35	200	15	133.2	30.2
	"	320	1.15	35	500	15	106.0	23.2
	drill	40	0.85	30	100	10	114.2	25.5
	"	80	1.00	30	80	8	91.1	25.3
	check	0	0.30	25	20	6	62.6	34.8
	spray	20	0.40	25	40	10	51.4	44.1
Corn	broadcast	40	0.40	8	8	8	38.7	
	"	80	0.50	10	10	10	55.8	
	"	160	0.80	10	25	10	96.0	
	"	320	1.25	25	100	10	48.1	
	drill	40	0.85	4	8	4	44.9	
	"	80	1.20	4	15	5	37.2	
	check	0	0.30	3	8	4	29.4	
	spray	20	0.40	4	8	4	46.5	

The data show that for Chehalis soil of moderate texture the optimum range for available boron, using sweet corn and field tomatoes as indicator plants, is approximately 0.5 to 0.8 ppm.

From the data showing the analyses of plant parts it is evident that boron tends to accumulate mostly in the leaves, secondly in the stems and least in the fruit. The leaves offer a more satisfactory criteria as an indication of optimum, toxic or deficient boron supply. For example, the available boron in the soil between 0.40 and 1.15 ppm. resulted in leaf boron accumulations of 80 to 500 ppm. but only a difference between 30 to 35 ppm. in the stem boron and 10 to 15 ppm. in the fruit boron of the tomato plant.

The yield of tomatoes from the plot receiving 80 pounds of borax per acre is low at 69.4 pounds since the leaf boron is 80 ppm. while the yield from the plot receiving 80 pounds of borax per acre by side-drill is 91.1 pounds of tomatoes. This may be explained by the higher percentage of cracked fruits in the former case, suggesting that other factors may be responsible for the discrepancy.

Data from the corn plot show a fairly consistent agreement between the 0.5 to 1.0 ppm. range set for the optimum limits of soil available boron, leaf boron analysis and yield. Comparison of the leaf boron analyses between the two crops shows that the tomato plant either requires more boron for its development or that the corn plant is more tolerant to the same soil concentration of boron.

GREENHOUSE EXPERIMENTS. - Melbourne Silty Clay Loam. In March, 1945, a series of 1/2 gallon pots of Melbourne silty clay loam was set up[1]. This soil, from the Camp Adair area, 10 miles north of Corvallis, had formerly been treated with excessive amounts of borax in an attempt to eradicate poison oak. Four treatments were applied in triplicate and distilled water added in an attempt to launder out the borax. Leachate from each pot was collected by gravity flow. The treatments were cropped and leached for two years. Sunflowers, alsike clover and bountiful beans were used as indicator plants. Beans were later selected as the most suitable crop and were grown to the flowering stage before harvesting for yield.

TABLE II. The most effective treatment for removing excess boron from the Melbourne soil was oak

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1. Mr. G. Schirk assisted in initiating these trials.

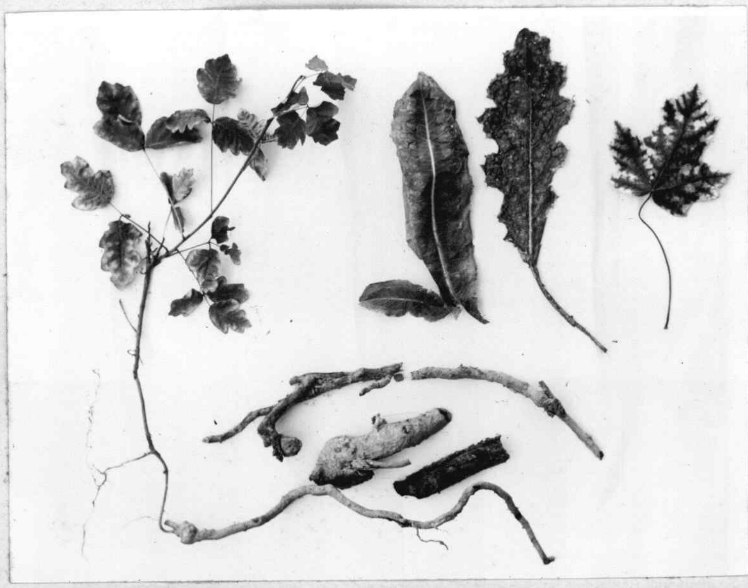


FIG. 1. Boron injury to oak leaves and roots (left) and to maple leaf (upper right) on Melbourne soil at Camp Adair.

FIG. 2. Leaching excess boron from Melbourne soil.

FIG. 3. Bountiful beans on Melbourne silty clay loam; 1-check; 6-manure, sulfur and lime; 8-manure and gypsum; 11-manure; 14-oak litter.

FIG. 4. Bountiful beans on Newberg sandy loam.

TABLE 2. EXCESS BORON REMOVAL BY SOIL TREATMENT & LEACHING
Melbourne silty clay loam

Period	Treatment	Rate T/ac	Average Leachate ml	Average Yields green gm	Average Yields dry gm	Available Soil Boron ppm.
Sunflowers						
March to	checks	-	455	none(4)		200
October,	M-S-L (1)	30-3-4	280	"		200
1945	M-G(2)	30-3	235	"		200
	M	30	345	"		200
	OL(3)	20	660	"		16
Alsike & Bountiful Beans						
October	checks	-	490	"		180
to	M-S-L	30-3-4	320	"		160
December,	M-G	30-3	300	"		175
1945	M	30	400	"		180
	OL	20	770	"		14
Bountiful Beans						
December	OL	10	760	none(5)		55
to	M-S-L-OL	30-3-4	465	"		40
March,	M-G-OL	30-3	390	"		43
1946	M-OL	30	490	"		185
	OL	30	875	20.5	6.9	8
Bountiful Beans						
March	OL	10	640	25.8	11.2	40
to	M-S-L-OL	30-3-4-10	545	34.8	16.0	25
May,	M-G-OL	30-3-10	660	32.8	15.0	32
1946	M	30	495	none(4)		100
	OL	30	925	40.6	24.3	6.5
Bountiful Beans						
May	OL	10	730	35.2	16.3	17
to	M-S-L-OL	30-3-4-10	690	41.7	24.7	13
September,	M-G-OL	30-3-10	780	36.5	20.8	12
1946	M	30	575	none(4)		81
	OL	30	930	45.2	29.7	2.8
Bountiful Beans						
September	OL	10	620	33.4	18.0	12.5
to	M-S-L-OL	60-6-8-20	825	37.0	19.2	9.5
December,	M-G-OL	60-6-20	875	37.6	22.2	7.0
1946	M	60	575	none(4)		65
	OL	30	935	48.5	32.5	1.5
Bountiful Beans						
December	OL	10	680	34.2	19.5	9.0
to	M-S-L-OL	60-6-8-20	870	35.8	20.1	7.5
March,	M-G-OL	60-6-20	910	40.6	24.3	4.0
1947	M	60	515	none(5)		50
	OL	30	980	52.7	36.0	1.1

(1)M-manure; S-sulphur; L-lime. (2) G-gypsum. (3)OL-oak litter. (4) sprouts died after germination. (5) some leaf development.

litter. Between March and October, 1945, the available boron concentration was reduced from 200 ppm. to 16 ppm. under that treatment. Thereafter further removals were slower, which seems logical due to the decreased concentration. The least effective in removing excess boron was the manure treatment. In the 2 year period between March, 1945, and March, 1947, the available boron was reduced only from 200 ppm. to 50 ppm. The effectiveness of the oak litter was further demonstrated during the period December to March, 1946, when oak litter was added to the checks. This was done to improve the physical condition of the soil in the check pots since it was very evident that cementation and channelling prevented an effective leaching process. The former check pots were reduced from 180 ppm. to 55 ppm. in the 4 month period. The manure-sulphur-lime and manure-gypsum combinations were not very effective in the 9 month period from March to December, 1945. Oak litter added to these treatments caused a greatly increased laundering effect.

The same amount of distilled water was added to each pot and the amount of leachate collected in each period is an indication of the porosity of the soil under each treatment. An exception to this is to be noted in the case of the original check pots in which the soil was continually hard and cracked so that channelling was difficult to avoid. Water was usually added every second day and any that did not infiltrate through the soil or used by the plant merely evaporated. The oak litter treatment imparted to the soil the greatest infiltration capacity. Manure was least effective in this respect.

Sunflower, alsike clover and Bountiful bean seeds all germinated in the highest available boron concentration of 200 ppm. In every case the sprouts yellowed and withered. A bean plant crop showing marked boron toxicity was obtained when the soil contained 40 ppm. of available boron. The leaves were yellow, the tissue brittle and stems very slender. Some faint toxicity symptoms were still evident when the soil showed 1.5 ppm. of available boron.

During the two year period of leaching approximately 6 litres of leachate were obtained from pots receiving oak litter only. The available boron was reduced to 1.1 ppm. The manure-gypsum-oak litter treatment at this time still contained 4.0 ppm. available boron. More than 4.1 liters of leachate were obtained therefrom. Leachate totals from other treatments were: checks, 4.4 litres; manure-sulfur-lime treatment, 3.9 litres; manure-gypsum treatment, 4.1 litres and manure treatment, 3.4

litres.

Beans grown on the oak litter treatment in the final trial showed signs of boron toxicity. Hence 1.1 ppm. available boron is above the maximum critical concentration.

Klamath Peat. Mid-November, 1945, a number of treatments were started in the greenhouse on Klamath Peat from the Experimental Station near Klamath Falls. This is an alkali peat containing toxic amounts of available boron. Series of 5-gallon jars were set up in such a way that leachate could be collected from each jar. All jars were first irrigated with an N-P-K solution. There were 3 treatments of 6 replicates each and 4 treatments of 4 replicates each.

The purpose of the experiment was to determine suitable method for laundering excessive boron from this soil. Following the treatments the jars were left to incubate for a 6-week period, then seeded to alsike clover and Banner oats. The clover yields are disregarded, since the growth was erratic in all treatments, and following the harvest of the more rapidly maturing oats as hay, the jars were continually infested with red spider and white fly.

Bountiful beans were grown later as an indicator crop for available boron levels in the various treatments. Composite soil samples were taken from each set of treatments for determining available soil boron when the beans were harvested.

TABLE III. The yield of Banner oat hay was doubled on the limed peat. The average yield per replicate from the lime and the sulphur treatments was 50.1 grams and 44.3 grams respectively in comparison to 24.5 grams from the check pots. The manure-lime combination was lower with 39.1 grams. The replicates treated with 180 pounds per acre of borax yielded 22.9 grams, slightly lower than the checks. The manure-sulphur combination was not as effective in raising the yield as were the manure and sulphur treatments individually.

Approximately 5.5 litres of leachate were collected from each replicate. The manure and sulphur treatments were most effective in reducing the initial pH of the peat from 9.03 to 7.29 and 7.75 respectively. Leaching the checks reduced the soil pH to 8.30.

There were 20 ppm. of available boron in the peat soil. The leaching process alone and leaching under the various treatments reduced the amounts of available boron in the peat. The most effective treatment was liming which tended to tie up part of the boron in unavailable

TABLE III. BORON REMOVAL BY SOIL TREATMENT AND LEACHING
Klamath Peat

Treatment Tons/acre	Nov. 1945 to May, 1946: Ave. Oat Hay Yield grams	Leachate litres	Soil pH (5)	Available Soil Boron ppm (6)	May to July, 1946: Average (4) Bean Yield grams	Leachate litres	Soil pH	Avail. Soil Boron ppm.
checks	24.5	5.5	8.30	13	30.3	2.3	8.30	10
30-manure (1)	38.0	5.7	7.29	5.5	35.1	2.0	7.27	3
30-manure (1) 1-sulphur	32.8	5.6	7.98	8	35.4	2.5	7.96	5
30-manure (1) 1-lime	39.1	5.5	8.33	8	29.1	2.0	8.30	6
1-sulphur (2)	44.3	5.5	7.75	15	39.4	2.0	7.50	9
2-gypsum (2)	37.2	- (3)	8.20	11	39.7	2.2	8.17	6
2-lime (2)	50.1	5.5	8.15	4.5	44.9	2.3	8.13	2.5
180 lbs. borax (2)	22.9	5.6	8.30	16	26.9	2.2	8.20	12

(1) 6 replications; (2) 4 replications; (3) 2 leachate jars leaked; (4) green weight of 7 bean plants; (5) average pH of each replicate; (6) determination on composite soil samples from each treatment.

form, thereby reducing the available boron to 4.5 ppm. at the end of May. Manuring proved effective in reducing the amount to 5.5 ppm. Manure-lime and manure-sulphur combinations reduced the available boron to 8 ppm. in both cases. Sulphur and gypsum treatments were least effective over the six months period in eliminating excess boron.

During the period May to July, 1946, the heaviest green growth of beans was obtained on the lime, gypsum and sulphur treatments with 44.9 grams, 39.7 grams and 39.4 grams respectively. Check growth was 30.3 grams. Yields from the manure-sulphur and manure-lime treatments were 35.4 and 29.1 grams respectively.

Approximately 2.2 litres of leachate were collected from each replicate. The manure and sulphur treatments were still the most effective in reducing the soil pH from 9.03 to 7.27 and 7.50 respectively.

Available boron was further reduced under the leaching process. Over the nine month period, available boron was reduced to 2.5 ppm. and 3 ppm. under the lime and manure treatments.

Boron toxicity symptoms were not evident in bean plants grown on the peat which had 2.5 and 3 ppm. available boron. Leaves of plants grown on all other jars containing higher amounts of available boron were brittle.

Newberg Sandy Loam. In November, 1945, a series of one-gallon jars containing Newberg sandy loam was set up in such a manner that the leachate from each replicate could be collected. The treatments comprised various rates of boron and the use of lime and sulphur to reduce and increase respectively, boron availability. There were 6 replicates of each treatment and Bountiful beans were grown as the indicator plant. All treatments received an initial irrigation with an N-P-K solution. Following application of the treatments the jars were incubated for 4 weeks before seeding.

TABLE IV. Boron deficiency symptoms were not evident in the bean plants grown on untreated Newberg sandy loam. This soil contains 0.4 ppm. of available boron. An application of 20 pounds per acre of boron as boric acid increased the available boron to 0.9 ppm. and proved to be excessive. The plants were stunted and the leaf petioles brittle, Heavier applications of 80 and 160 pounds per acre of boron increased the available boron to 1.2 and 1.8 ppm. which caused even more marked toxicity symptoms. However, the application of 2 tons per acre of lime with 20 pounds per acre of boron resulted in the soil having 0.5 ppm. of available boron. Plant yield on this treatment increased to 40.5 grams green

TABLE IV. OPTIMUM AVAILABLE BORON RANGE IN NEWBERG SANDY LOAM

Treatment per acre	Soil pH	Available Soil Boron (1) ppm.	Average Leachate litres	Average Yields Green Wt.(2) grams	Average Yields Dry Wt. grams	Leaf Boron ppm.
checks	5.9	0.4	1.0	32.6	11.9	32
20 lbs. boron	5.9	0.9	1.1	15.6	11.1	120
80 lbs boron	5.9	1.2	1.1	11.0	7.6	270
160 lbs boron	5.9	1.8	1.0	6.3	4.8	800
2 tons lime	6.1	0.4	1.0	30.6	10.6	27
2 tons sulfur	5.9	0.4	1.1	33.5	12.6	35
20 lbs boron 2 tons lime	6.1	0.5	1.2	40.5	19.7	40
20 lbs boron 2 tons sulfur	5.8	1.0	1.0	13.0	8.9	130

(1) Determinations made on composite samples from each treatment.

(2) 5 plants per replicate.

weight compared to 32.6 grams from the check pots.

The sulphur treatment failed to increase the available boron above 0.4 ppm., the same value obtained for the untreated soil. Since the treatment only lasted three months it is quite possible that this period was too short to permit complete oxidation of the sulphur to sulphuric acid or that the treatment was too small to permit an effective increase in acidity. Plant yield from this treatment was 33.5 grams green weight which is comparatively the same as 32.6 grams obtained from the check pots.

The boron-sulphur treatment resulted in an increase of 0.1 pH and the available boron was 1.0 ppm. compared to 0.9 ppm. when the same application of boron, 20 pounds per acre, was alone added.

Leaf boron analyses of the bean plants reflect the available soil boron analyses. Rapid increases in boron accumulation in the leaves are shown with small increases in available soil boron.

The lower critical concentration of available boron is about 0.5 ppm. The upper limit is below 0.9 ppm. in this soil using the Bountiful bean as an indicator plant.

Camas Gravelly Loam. In March, 1946, a series of 5-gallon pots were set up in the greenhouse containing

Camas gravelly loam from the Horticulture Farm. This soil was first screened through a 5-mesh sieve to remove the coarse gravel. After irrigating the soil with an N-P-K solution various treatments were applied to determine the optimum available boron concentration for Camas gravelly loam. Bountiful bean plants grown to the flowering stage were used as a plant indicator. The treatments included lime and sulphur to decrease and increase the available boron supply. There were 4 replicates in each treatment. Following the application of the treatments the pots were incubated for 4 weeks before seeding. Leachate was not collected but the soil was kept moist regularly by additions of distilled water.

TABLE V. Bean plants grown on the check pots did not show any foliar evidence of a boron deficiency. The yield was 30.1 grams, green weight. An application of 10 pounds of boron per acre increased the plant growth to 47.3 grams, green weight. Available boron was increased from 0.3 ppm. in the untreated soil to 0.5 ppm. When the boron applications were increased to 20 and 40 pounds per acre the yields were depressed to 25.2 and 19.0 grams, green weight, respectively, and the plants showed marked foliar evidence of boron toxicity. Available soil boron in these two treatments was 0.9 and 1.2

TABLE V. OPTIMUM AND AVAILABLE BORON RANGE IN CAMAS GRAVELLY LOAM

Treatment	SOIL pH	Available Soil Boron[1]	Average Yields[2] Green Wt.	Dry Wt.	Leaf Boron
per acre		ppm.	grams	grams	ppm.
checks	6.0	0.3	30.1	10.5	25
10 lbs boron[3]	6.0	0.5	47.3	22.9	40
20 lbs boron	6.0	0.9	25.2	9.2	130
40 lbs boron	6.0	1.2	19.0	8.3	220
80 lbs boron	6.0	1.6	----	---	---
160 lbs boron	6.0	2.0	----	---	---
20 lbs boron 2 tons lime	6.1	0.7	40.5	16.1	80
20 lbs boron 2 tons sulfur	6.0	0.9	26.5	9.3	140

(1) Determinations made on composite samples from each treatment.

(2) Average of 7 plants per replicate.

(3) Boron applied as boric acid.

ppm. in that order. There was no plant development on the soils receiving 80 and 160 pounds of boron per acre.

Two tons of lime applied with 20 pounds per acre of boron reduced the available boron to a safe concentration. Plant growth on this treatment was 40.5 grams, green weight, and the available soil boron 0.7 ppm. The foliage showed no sign of boron toxicity. The effect of adding 2 tons per acre of sulphur with 20 pounds of boron was not detectable in the soil or plant analyses. The 4 month period was not long enough for the sulphur to undergo oxidation to any effective degree.

Boron accumulations in the plant leaf increased from 25 ppm. for plants grown in soil with 0.3 ppm. available boron to 220 ppm. for plants grown in soil with 1.2 ppm.

Camas gravelly loam is low in available boron and the indicator plant responded significantly to an application of 10 pounds per acre of boron. Available soil boron was increased from 0.3 to 0.5 ppm. At 0.7 ppm. the green weight was slightly lower at 40.5 grams and at 0.9 ppm. marked toxicity was indicated. The optimum range for available boron in this soil appears to be from approximately 0.5 to 0.7 ppm.

Chehalis Silty Clay Loam. In March, 1946, a series of gallon jars was set up in the greenhouse containing

Chehalis silty clay loam from the Horticulture Farm. The soil was irrigated with an N-P-K solution before treatments were applied to determine the optimum available boron concentration for Chehalis silty clay loam. Bountiful bean plants were grown to the flowering stage as a plant indicator. The treatments included boric acid, lime, sulphur and ammonium nitrate. The latter salt was tried to determine the effect of nitrogen on reducing boron toxicity. There were 5 replicates in each treatment. Following the application of the treatments the jars were incubated for 4 weeks before seeding. No leachate was collected but the soil was kept moist regularly by additions of distilled water.

TABLE VI. Available boron in the untreated soil was 0.4 ppm. The yield of bean plants from this soil was 40.2 grams green weight. Applications of 5 and 10 pounds per acre of boron as boric acid increased the available soil boron to 0.6 and 0.7 ppm. and the green weight to 53.1 grams and 49.1 grams respectively. Bean plants produced on soil receiving 20 pounds per acre of boron showed toxicity symptoms and the green weight of plants dropped to 33.5 grams. The available boron of the latter soil was determined as 0.9 ppm. An application of 40 pounds per acre increased the available soil

TABLE VI. OPTIMUM AVAILABLE BORON RANGE IN CHEHALIS SILTY CLAY LOAM.

Treatment	Soil pH	Available Soil Boron(1)	AVERAGE YIELDS(2) Green Wt.	Dry Wt.	Leaf Boron
per acre		ppm.	grams	grams	ppm.
checks	6.2	0.4	40.2	11.2	30
5 lbs boron(3)	6.2	0.6	53.1	16.3	50
10 lbs boron	6.2	0.7	49.1	13.3	60
20 lbs boron	6.2	0.9	33.5	10.9	130
40 lbs boron	6.2	1.7	----	----	--
10 lbs boron 2 tons lime	6.3	0.4	36.6	10.9	35
10 lbs boron 2 tons sulfur	6.2	0.7	48.2	11.9	65
20 lbs boron 100 lbs ammonium nitrate	6.1	0.9	46.5	21.1	110

(1) Determinations made on composite samples from each treatment.

(2) Average of 7 plants per replicate.

(3) Boron applied as boric acid.

boron to 1.7 ppm. which proved too toxic for plant growth. The sprouts from the germinated seeds yellowed and died.

Lime applied with boron apparently reduced the available boron below the critical concentration to 0.4 ppm. The green weight yield from this treatment dropped to 36.6 grams. Sulphur was not effective in increasing available soil boron over the 4 month period. This is evident from a comparison of the soil and plant analyses from the 2 treatments, using 10 pounds of boron and 10 pounds of boron with 2 tons of sulphur per acre.

The data from the treatment using ammonium nitrate to reduce boron toxicity is not conclusive since only the one trial was run. This trial in which 100 pounds of ammonium nitrate and 20 pounds of boron per acre were applied seemed to offset the toxic effect of 0.9 ppm. of available boron. The plant green weight yield was 46.5 grams compared with 33.5 grams from the treatment involving the addition of 20 pounds of boron alone. There was no sign of toxicity in the plants from the treatment.

Soil reaction was pH 6.2 in all treatments except where lime was added, causing an increase to 6.3, and where ammonium nitrate was added causing a decrease in pH to 6.1.

Leaf concentrations of boron in the indicator plants increased with the rise in available soil boron.

The optimum range of available boron in this soil is probably between 0.5 and 0.8 ppm.

GERMINATION TESTS. The relationship between boron concentration and germination in media of high, moderate and extremely low base exchange capacity was studied. High test seed samples of field peas, Hannschen barley, Banner oats, sunflowers, sweet corn, alsike clover, Bountiful beans and Grimm alfalfa were used. Three hundred seeds were used for each determination. Pure sand of extremely low base exchange capacity, Chehalis silty clay loam of moderate exchange capacity and Klamath peat of high exchange capacity were air-dried and weighed out into porcelain dishes to serve as germination beds. The beds were then brought up to a definite weight by the addition of a boric acid solution of such concentration to provide the required amount of boron and sufficient liquid to thoroughly saturate the soil. The presence of free liquid was avoided. The seeds were imbedded in the soil and the dishes placed in a thermostat controlled chamber with a glass top. The temperature was maintained at 30°C. and the atmosphere of the chamber kept saturated by pans of water below the germination beds in order to minimize evaporation. At the end of 24 hours each dish was weighed to determine whether any evaporation had taken place which would alter the boron concentration. When necessary, distilled water was added as a fine spray over the soil to recover the required weight.

Each test lasted 48 hours, then the seeds removed by hand or the dishes flushed with water to float the seeds. Germinated seeds were counted from which was computed the percentage germination for each test. The results of the tests are presented in Table 7 and Figure 5.

TABLE VII. Germination did not increase with increase in boron in any concentration with the eight kinds of seed and the three types of soil media used in the experiment. The base exchange capacity of pure sand is practically nil and the percentage germination of two crops, barley and oats, dropped to 72 and 88 per cent respectively on addition of 5 ppm. of boron. The other crops were relatively unaffected at this concentration, but all fell below 90 per cent at 20 ppm.

The base exchange capacity of Chehalis silty clay loam is 14.7 milliequivalents per 100 grams. The total boron concentrations could be effectively increased before seriously reducing germination. Thus at 30 ppm.

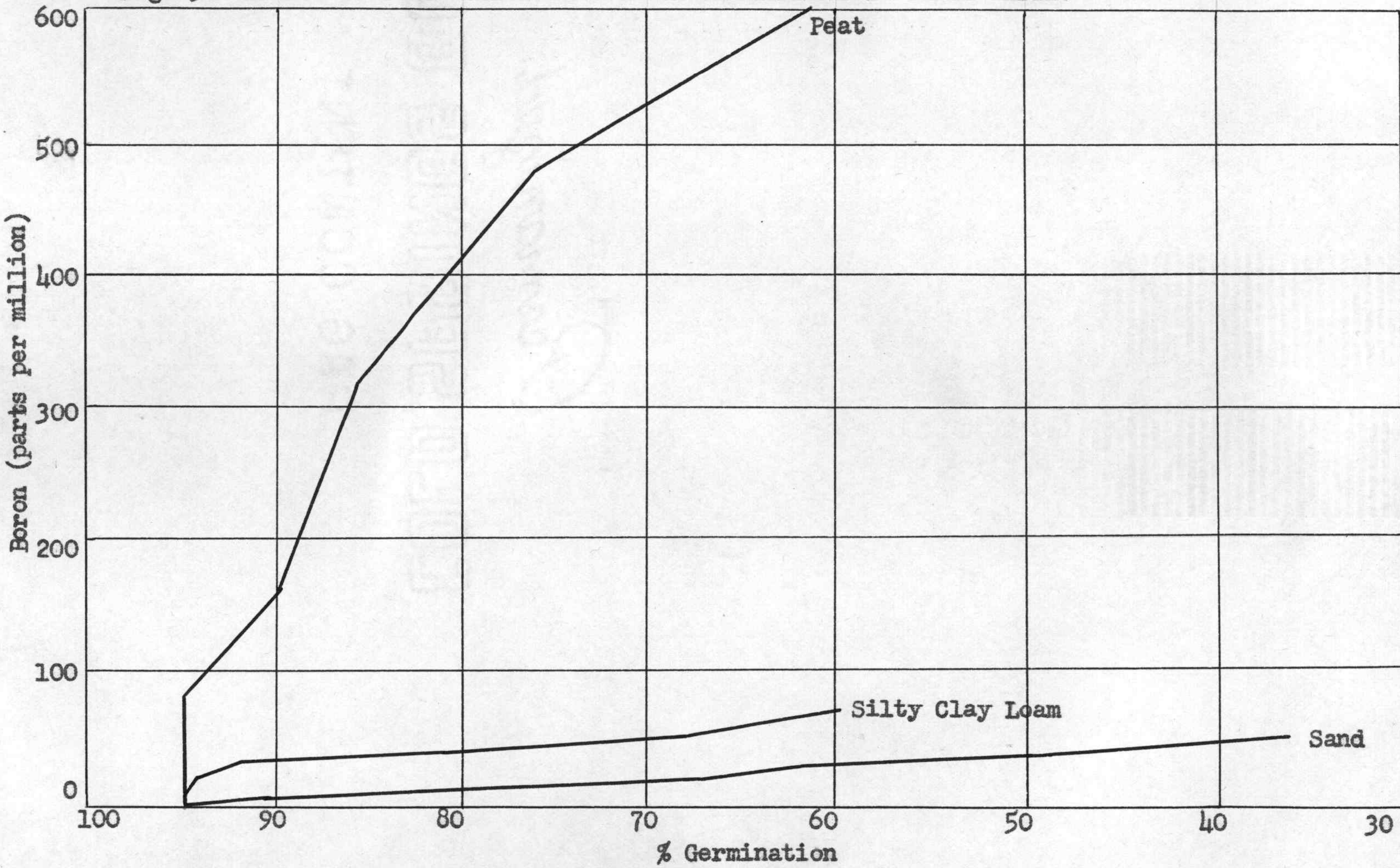
TABLE VII. RELATION OF TOTAL BORON TO GERMINATION IN THREE MEDIA

SOIL	Boron Added		Per Cent Germination at 48 Hours								
	lbs./acre	ppm.	Peas	Barley	Oats	Sunflowers	Corn	Alsika	Beans	Alfalfa	Average
Pure sand	0	0	95*	93	94*	96	95	96	95	95	95
	10	5	95*	72*	88*	94	96*	95*	95	96*	91
	20	10	92	55	80	90	84	80	87	95	83
	40	20	81	31	45	65	71	75	80	88	67
	60	30	89		30	52	52	60	70	82	62
	80	40	62			32	30	42	52	74	49
	100	50	32					28	35	53	37
Chehalis silty clay loam	0	0	95	95	95	94*	95	98	95*	97	95
	10	5	96*	95*	92	96*	95	97	96*	96	95
	20	10	95	96*	94	95	96	95	96*	97	95
	40	20	95	91	90	92	94	96	95	94	94
	60	30	96	85	85	90	90	96	95	95	92
	80	40	95	42	62	81	84	95	94	93	81
	100	50	53	36	45	72	70	95	90	82	68
	140	70			38	48	42	85	76	70	60
Klamath peat	0	0	95	95*	95*	96	95	95	96	95*	95
	80	80	95	96*	96*	96	95	95	94	96*	95
	160	160	86	88	85	88	94	92	95	95	90
	320	320	84	80	82	80	82	95	90	94	86
	480	480	82	71	68	72	70	84	79	82	76
	600	600	70	43	50	58	54	73	71	72	61

*Average of 5 replications.

E

Fig. 5. EFFECT OF BORON CONCENTRATION ON GERMINATION IN THREE MEDIA.



only oats and barley had dropped below 90 per cent to 85 per cent germination. The other seven crops remained at 90 per cent or above. Alsike clover was able to maintain a fairly high germination rate, 85 per cent after the addition of 70 ppm. of boron.

Klamath peat has a relatively high base exchange capacity of 75 milliequivalents per 100 grams. With the addition of 80 ppm. of boron, the percentage germination for all eight crops varied between 94 to 96 per cent. At 320 ppm. of boron, alsike, beans and alfalfa remained at 90 per cent germination or better.

Of the eight crops the legumes, peas, alsike, beans and alfalfa were most persistent in germination at high total boron concentrations. Sunflowers and corn were next, followed by oats and barley.

The data indicate that Klamath peat possesses a higher optimum and critical boron concentration range than do the lighter soils. Similarly Chehalis silty clay loam has a higher range than the sandy soils.

EFFECT OF AVAILABLE SOIL BORON ON THE NITROGEN CONTENT OF PLANTS. Considerable plant material was saved from the preceding experiments in field and greenhouse already described earlier in this paper. The plant parts were subjected to Kjeldahl determinations for nitrogen content to learn what effect the available soil boron concentrations had on the nitrogen content of plant tissue.

Tomatoes and sweet corn grown on the boron plots at the Horticultural Farm were sampled. The plant parts, namely stems, leaves and fruits, were sampled from each treatment, dried at 50oC. and ground to pass a 100-mesh sieve. Nitrogen determinations were then run in duplicate on each sample. These data are recorded in Table 8.

Bean plants harvested from greenhouse experiments were similarly prepared. Nitrogen determinations were made on leaf tissue only. These data are recorded in Table 9.

TABLE VIII. Stems, leaves and fruit of tomato plants grown on check plots of Chehalis silty clay loam contain less nitrogen with one exception than those plants grown on the plots treated with borax applied by broadcasting. There is a consistent increase in the nitrogen content of the stems as the rate of borax applied by broadcast was increased. Nitrogen content of leaves and fruit show no consistent rise in this case. Stems, leaves and fruit of plants fertilized with 80 pounds of borax applied by drill contain more nitrogen than those plants grown on the plot fertilized with 40 pounds of

TABLE VIII. RELATION OF AVAILABLE SOIL BORON AND PLANT NITROGEN.

Field Study on Chehalis Silty Clay Loam

Soil Treatment	Soil Avail. B.	Stems B	Stems N	Leaves B	Leaves N	Fruit B	Fruit N
Borax lb./acre	ppm.	ppm.	per cent	ppm.	per cent	ppm.	per cent
TOMATOES							
40-broadcast	0.40	30	1.97	80	4.22	10	2.26
80- "	0.50	35	2.02	80	4.26	10	2.30
160- "	0.80	35	2.08	200	4.24	15	2.29
320- "	1.15	35	2.11	500	4.26	15	2.26
40-drilled	0.85	35	1.81	100	4.04	10	2.21
80-drilled	1.00	30	1.99	80	4.08	8	2.58
20-spray	0.40	25	1.86	40	4.26	10	2.17
check	0.30	25	1.97	20	4.20	6	2.21
SWEET CORN							
40-broadcast	0.40	8	0.80	8	2.50	8 (1)	3.19
80- "	0.50	10	0.86	10	2.55	10	3.39
160- "	0.80	10	0.82	25	2.53	10	3.51
320- "	1.15	25	0.87	100	2.59	10	3.72
40-drilled	0.85	4	0.85	8	2.73	4	3.19
80- "	1.00	4	0.90	15	2.65	5	3.24
20-spray	0.40	4	0.80	8	2.48	4	3.13
check	0.30	3	0.78	8	1.91	4	3.05

(1) Kernels only.

borax applied in the same manner, however, the latter plants contain less nitrogen than those grown on the check plots even though the available soil boron was greater at the locations of sampling. The spray, drill and broadcast methods are not comparable in available soil boron or plant nitrogen.

Nitrogen content of the sweet corn stems, leaves and fruits are consistently higher on all the borax treated plots whether fertilized by broadcast, drill or spray. However, the nitrogen content of the plant parts do not increase consistently as the available soil boron and tissue boron increases. Nevertheless, in all cases the plant parts produced on the plot treated with 320 pounds of borax applied by broadcast contain more nitrogen than do those grown on the 40 pound plot treated in the same manner. The available soil boron in these plots is 0.40 and 1.15 ppm. respectively.

TABLE IX. Bountiful beans were grown to the flowering stage only, under greenhouse conditions on Chehalis silty clay loam and Camas gravelly loam. These analyses show a consistent rise in leaf nitrogen and leaf boron as available soil boron increased. The regularity of these results over the inconsistent results in Table 8 may be due to the time of sampling the plant parts or to the difference in growth conditions between outdoor and greenhouse or both.

TABLE IX. RELATION OF AVAILABLE SOIL BORON AND PLANT NITROGEN.
Greenhouse Study

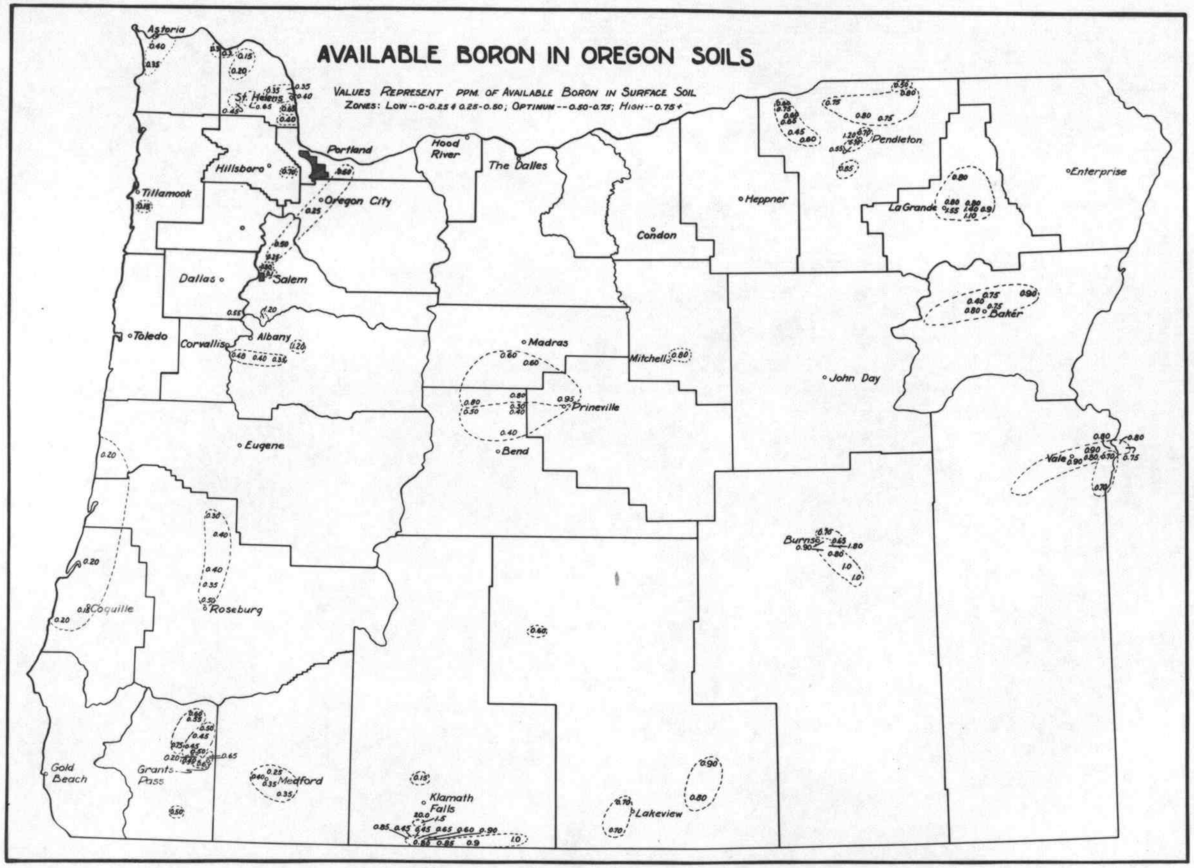
Soil Treatment	Chehalis silty clay loam			Camas gravelly loam		
	Available Soil Boron	Bean Leaf B.	Bean Leaf N.	Available Soil Boron	Bean leaf B.	Bean leaf N.
lbs./acre	ppm.	ppm.	per cent	ppm.	ppm.	per cent
checks	0.4	30	2.97	0.3	25	2.92
5-boron(1)	0.6	50	3.27			
10-boron	0.7	60	3.64	0.5	40	2.94
20-boron				0.9	130	3.19
40-boron				1.2	220	4.24

(1) as boric acid.

BORON AVAILABILITY MAP OF OREGON SOILS. Approximately 150 soil samples from various agricultural areas in the state were analyzed for available boron. Official samples were used mostly in this survey. Some of these soils are from sections of the state yet to be mapped and the soils classified. In such cases there is no soil name. Many of the samples from any one location are available to varying depths and the available boron determination has been run on these samples. However, only the available boron of the soil surface usually to plow depth was used in the zoning of the state as to its available boron content.

The results of these analyses are summarized on the map depicted in Figure 6. A complete list of all determinations is appended in the Appendix at the end of this paper.

FIG. 6


AVAILABLE BORON IN OREGON SOILS
VALUES REPRESENT PPM. OF AVAILABLE BORON IN SURFACE SOIL
ZONES: LOW--0-0.25 & 0.25-0.50; OPTIMUM--0.50-0.75; HIGH--0.75+
Astoria
St. Helens
Portland
Hood River
The Dalles
Hillsboro
Tillamook
Oregon City
Heppner
Pendleton
Enterprise
La Grande
Condon
Dallas
Salem
Baker
Toledo
Corvallis
Albany
Madras
Mitchell
John Day
Prineville
Bend
Eugene
Vale
Burns
Coquille
Roseburg
Gold Beach
Grants Pass
Medford
Klamath Falls
Lakeview

DISCUSSION

LOW, OPTIMUM AND HIGH CONCENTRATIONS. Field and greenhouse experiments indicate that three typical Western Oregon soils may be slightly deficient in available boron. These soils, Chehalis silty clay loam, Camas gravelly loam and Newberg sandy loam produced no boron deficiency symptoms in the indicator plants grown thereon but greater growth was obtained when the available boron was increased to 0.5 ppm. This was set as the dividing line between boron-deficient and boron-adequate soils. Woodbridge (1940) reported that soils should contain 0.5 ppm. of available boron to satisfy normal crop requirements. However Reeve et al (1944) set 0.350 ppm. as the lower division point on the basis of field and greenhouse tests using the turnip as an indicator plant. Piland et al (1944) investigating boron deficiency in sandy North Carolina soils found the average available soil boron concentration to be 0.24 to 0.35 ppm.

There can be no arbitrary range for available boron concentration due to variations in tolerance to, and requirements for boron by different types of plants. This was substantiated by Eaton and Wilcox (1939) who state that concentrations of available boron insufficient to support normal plant growth are usually below 0.1 to 0.5 ppm. The maximum optimum concentration for the three Oregon soils is about 0.75 ppm. Between 0.7 to 0.9 ppm. and higher, bean plants showed evidence of injury. Eaton and Wilcox report that concentrations of available boron likely to cause injury are usually in excess of 0.5 to 5.0 ppm. Bean plants grown on Melbourne silty clay loam having 1.1 ppm. of available boron showed marked foliar injury.

Another factor to be considered in establishing deficient, optimum and toxic concentrations is soil type. For example, Klamath peat having an available boron content of 2.5 ppm. produced bean plants normal in appearance and with no evidence of injury. This organic soil, because of its relatively high pH, base exchange capacity and colloid content, has a higher available boron range within which beans were not injured. On the other hand, lighter textured soils have a lower optimum range. Boron injury is more likely to occur with sandy soils, than with loams and clay loams in that order. Hanna and Purvis (1938) report that the tolerance of soils to various rates of borax treatment is correlated with the exchange capacity of the soil and with the amount of available boron present.

REMOVAL OF EXCESS BORON. Heavy applications of borax on Melbourne silty clay loam at Camp Adair caused widespread injury to all vegetation. Available boron in this soil was 20 ppm. Greenhouse tests revealed that heavy applications of oak litter to the soil which was subjected to constant leaching made possible a fairly rapid removal of excess boron. Manure treatments were not effective but rather appeared to retain the boron like a sponge. Lime, sulfur and gypsum were less effective than oak litter.

Greenhouse experiments demonstrated that lime reduced the available boron concentration. There is disagreement in the literature regarding the reason for this reaction. Ferguson and Wright (1940) pointed out that the fixation of boron may happen in one of three ways, namely, lime may fix boron into some insoluble or slightly soluble form; lime increases the soil pH and thereby may reduce the ability of the root to absorb boron; lime may stimulate the growth of soil microorganisms until there is competition between them and the plant for soil boron. Naftel (1937) has reported that boron fixation is due to the stimulation of growth of soil microorganisms resulting in the available boron being largely used in the metabolism of the organisms. Midgely and Dunklee (1940) on the other hand report that the fixation is chemical rather than biological.

Leaching proved to be a slower but nevertheless effective method of laundering excess boron from the soil. Purvis and Hanna (1938) studying the residual effects of borax applied to field plots indicated that it was readily removed by leaching, from Norfolk sandy loam.

FACTORS EFFECTING GERMINATION. Germination tests in various media indicated that soil type was an important factor in establishing toxic boron concentrations. Boric acid applications did not increase the germination but rather decreased it. The concentration at which major decreases set in depended on the soil type. Sand, having no base exchange capacity or colloid content had the lowest toxic concentration value, namely, 10 ppm. Chehalis silty clay loam was next with 20 to 30 ppm. and Klamath peat the highest with more than 80 ppm.

This is explained as being due to their respective fixing power of boron from boric acid solutions. This phenomenon of fixing reduces the available boron concentrations. Reeve et al (1944) report that loam and silt loam soils were able to fix a great deal more boron than the sands and sandy loams.

High test seed should contain adequate amounts of boron for normal germination. Piland and Ireland (1941) report that alfalfa grown on a deficient soil containing only 0.19 ppm. available boron produced poor seed yields. An application of 20 pounds per acre of borax corrected this condition and normal seed production followed. Therefore it is not surprising that boric acid did not increase percentage germination of normal seed. An early publication by Morel (1910) reported that the germination of corn and wheat kernels soaked in weak solutions of boric acid and borax was actually retarded in soil and sand. The effects were in proportion to strength of solution and length of time of soaking.

EFFECT OF AVAILABLE BORON ON PLANT NITROGEN. Analyses of stem, leaf and fruit parts of sweet corn and tomatoes grown on Chehalis silty clay loam in the field indicate that the nitrogen content of those parts is higher at toxic accumulations of boron than in those parts containing normal concentrations of boron. Greenhouse tests under controlled conditions using the bean plant revealed a consistent increase in leaf nitrogen with increased leaf boron content. However, the data do not show any evidence of a total nitrogen/boron ratio in the leaf. Sanders (1944) reported that increased boron content of alfalfa hay in the field sometimes increased and sometimes decreased the nitrogen content of the hay. Sand culture studies at the Kentucky Experiment Station (1945) indicated that the insoluble or protein nitrogen of spinach increased in a regular fashion as the boron concentration in the nutrient solution was increased.

AVAILABLE BORON OF OREGON SOILS. During the past few years investigators have adopted the practice of presenting minor element deficiency data directly on state or county maps. Publications by Colwell and Baker (1939), Reeve et al (1944) and Coleman (1945) are only three examples of this practice found in the literature. Beeson (1945) has summarized all known areas in the United States where minor element deficiencies including boron have been reported.

Dregne and Powers (1942) presented an outline map of Oregon showing areas where boron deficiency has been recognized. Since then the author has extended this survey of available boron in Oregon soils. Over 200 soils from agricultural areas of the state have been analyzed for available boron. On the basis of fixed and greenhouse studies approximate minimum and maximum critical boron concentrations for soils have been established at 0.5 ppm. and 0.75 ppm. respectively with the optimum range between those values. As already discussed, the optimum range cannot be fixed since it is dependent on soil type and plant tolerance to boron. However the 0.5-0.75 ppm. range seems to be optimum for medium textured soils which prevail in the state. On this basis the availability map has been zoned into low, optimum and high regions so far as soil available boron is concerned. Low availability areas may or may not be deficient in boron, similarly high availability does not necessarily imply that those areas are toxic. The plant is the best indicator for determining deficient and toxic concentrations and more extensive field tests will add greatly to the information alreadyaccumulated on this subject.

A study of the availability map reveals that boron deficiency is prevalent in the humid north-west part of Oregon. Leaching, the use of highly refined commercial fertilizers and cultivation have brought about this condition. The soils of Eastern Oregon are generally less subject to leaching. Analyses of many of these soils indicate a relatively high content of available boron prevails. Apparently the boron is present with the unleached tetraborate. A few pedalfers and leached sandy soils of basaltic origin that have been copiously irrigated from six to eight decades show crop response to applications of boric acid or borax.

FIG. 7. Boron injury to oak trees on Melbourne soil at Camp Adair.

FIG. 8. Boron injury to sweet corn on Newberg sandy loam at the Horticulture Farm.

FIG. 9. Alfalfa seedlings on Camas gravelly loam; x-check, Ex. B. - 40 pounds boron per acre.

FIG. 10. Boron plots at Horticulture Farm. Front row- tomatoes, second row-sweet corn. Left, 160 pounds borax per acre (broadcast); centre 360 pounds borax per acre (broadcast); right, 40 pounds borax per acre (side-drill).

SUMMARY

A review of the literature summarizes the compounds and availability of soil boron; the role of boron in animal and microbiological nutrition; the historical background of boron investigations and the essential nature of boron in plant nutrition.

Field and greenhouse investigations indicate the low and high optimum available boron concentrations in medium-textured soils to be 0.50 ppm. and 0.75 ppm. respectively.

Sandy soils have a lower optimum range of concentration for available boron than medium-textured soils, while those having a heavier texture, high colloid content and base exchange capacity have a higher optimum available boron range.

Bountiful beans grown to the flowering stage proved to be excellent indicator plants. Growth was rapid and the broad leaves readily revealed any deficiency or toxicity symptoms.

The determination of leaf boron is the best criterion for establishing deficient, optimum and toxic boron supply. Slight differences in available soil boron effect the amount of leaf boron to a marked degree whereas the stem and fruit tissues are less subject to boron accumulation.

Toxic concentrations of boron were most readily removed from Melbourne silty clay loam by the use of oak litter and continuous leaching. Manure treatments were least effective under leaching. Excess available boron in Klamath peat was best reduced by the use of lime. Manure, with leaching was only slightly less effective in laundering out the boron. Leaching the untreated soils with water removed a considerable part of the available boron.

Germination tests with eight different crops and three different media, sand, silty clay loam and peat with varying concentrations of boron revealed that sand was least effective in fixing soluble boron and the peat most effective. Legumes were more tolerant to high boron concentrations than sunflowers, corn, oats and barley in that order.

Nitrogen content of plant parts grown under field and greenhouse conditions was slightly higher than that of plant parts from soil receiving no added borax. Bean leaves from plants grown on soil treated with increasing amounts of borax contained increasing amounts of boron and nitrogen. However there was no evidence of a boron-nitrogen ratio.

Over 200 soils from various agricultural areas in Oregon were analyzed for available boron. The results were mapped and the state zoned into low, optimum and high available boron areas.

BIBLIOGRAPHY

1. Agulhon, H. Emploi du Bore comme Engrais Catalytique. Compts. Rendus Acad. Sci. 150:288-291.

2. Baumert, G. Zur Frage des normalen Vorkommen der Borsäure im Weine. Ber. Deut. Chem. Gesell. 21:3290-3292.

3. Beeson, K. C. The occurrence of mineral nutritional diseases of plants and animals in the United States. Soil Sc. 60:9-13.

4. Berger, K. C., and Truog, E. Boron determinations in soils and plants, using the quinalizarin reaction. Ind. Eng. Chem. (Anal. Ed.) 11: 540-554.

5. Bertrand, G. Les engrais complementaires. Chem. Ztg. 27:613-614.

6. Bertrand, G. Sur le role des infiniment petits produits chemique en agriculture. Conf. 8e, Cong. Internatl. Chim. Appl., N.Y.

7. Bertrand, G., and Agulhon, H. Normal presence of boron in animals. Compt. Rend. Acad. Sci. 155:248-251.

8. ------------- and ----------. Presence of boron in animals. Compt. Rend. Acad. Sci. 156:732-735, No. 9.

9. Bertrand, G. Biological importance of boron-particularly in good plant growth. Rec. Trav. Chem. Pays-Bas. 57:569-574.

10. Boseken, J., and Waterman, H. I. Influence of boric acid and some other compounds on the development of Penicillium glaucum and Aspergalus niger. Folia Microbiol. (Defft) 1, No. 3, 17 pp.

11. Bouquet, A. G. B., and Powers, W. L. Celery stem crack and use of boron in its control. Ore. Sta. Circ. Inform. 194.

12. Brenchley, W. E., and Thornton, H. G. The relation between the development, structure and functioning of the nodules on Vicia faba, as influenced by the presence or absence of boron. Roy. Soc. London Proc. Ser. B. 98: 391-399.

13. Brenchley and Warrington. The feeding of the plant. Rothamsted Expt. Sta. Rpt. 1921-1922:14-16.

14. Callison, J. A. The distribution of boracic acid among plants. Jour. Analyt. Chem 4:191-197.

15. Coleman, R. Boron content of Mississippi soils and plants. Better Crops with Plant Food, June, 1946, 4 pp.

16. Colwell, W. E., and Baker. G. O. Studies of boron deficiencies in Idaho soils. Amer. Soc. Agron. Journ. 31:503-512, illus.

17. Connor, S. D., and Fergus, E. N. Borax in fertilizers. Ind. Expt. Sta. Bull. 239, 15 pp, illus.

18. Cook, F. C. Boron: its absorption and distribution in plants and its effect on growth. Jour. Agr. Res. 5, No. 19, pp. 877-899.

19. Crampton, C. A. Borsäure als Bestandthiel der Pflanzen. Ber. Deut. Chem. Gesell. 2:1072-1076.

20. Dennis, R. W., and O'Brien, D. G. Boron in Agriculture West of Scotland Agric. Col. Res. Bull. 5, 98 pp.

21. Directors Report, Kent. Ag. Exp. Sta. 57th Ann. Rpt. pp. 34, 47-48, 59.

22. Drake, M., D. H. Sieling and G. D. Searseth. Calcium-boron ratio as an important factor in controlling the boron starvation of plants. J. Am. Soc. Agron. 33:454-462.

23. Dregne, H. E., and Powers, W. L. Boron fertilization of alfalfa and other legumes in Oregon. Amer. Soc. Agron. Jour. 54:902-912.

24. Dufrenoy, J. Deficiency of boron in plants. Compt. Rend. 17th Congr. chim. ind., Paris, Sept-Oct. 1937, pp. 746-751.

25. Eaton, F. M. Interrelations in effects of boron and indcle-acetic acid on plant growth. Bot. Gaz. 101:700-705.

26. ------------ Deficiency, toxicity and accumulation of boron in plants. J. Ag. Res. 69:237.

27. Eaton, F. M., and Wilcox, L. V. The behavior of boron in soils. U.S.D.A. Tech. Bull. 696:1-58.

28. Ferguson, W., and Wright, L. E. Micro-element studies with special reference to the element boron. Sci. Agric. 20:470-487.

29. Foote, F. J., and McElhiney, J. B. Effect of available nitrogen in soil on sulfate and boron in lemon leaves. Calif. Citrograph 22:346 and 378-380.

30. Haddock, J. L., and Vandecaveye, S. C. Yield and chemical composition of alfalfa on two Western Washington soil types. Soil Sc. Soc. Amer. Proc. 10:129-133.

31. Hanna, W. J., and Purvis, E. R. The susceptibility of various plants to boron toxicity as influenced by soil type. Soil Sc. Soc. Proc., vol. 3, pp. 205-209.

32. Hanna, W. J., and Purvis, E. R. Effect of borax and lime on activity of soil micro-organisms in Norfolk fine sandy loam. Soil Sc. 52:275-280.

33. Hasler, A. Boron content of soils and rocks. Landw. Jahob. Schweiz 56:486-498.

34. Herzinger, F. The sphere of activity of boron. Bodenkunde und Pflanzernahr 26, 1940.

35. Hotter, E. Ueber das Vorkommen des Bors im Pflanzenreich und dessen physiologische Bedeutung. Landw. Vers. Sta. 37:437-458.

36. Hove, E. C., Elvehjem, C. A., and Hart, E. B. Boron in animal nutrition. Amer. J. of Physiol. 127:689-701.

37. Hughes, W. L., and McLean, R. C. The quantitative distribution of boron in Vicia faba and Gossypium herbacium. Ann. Appl. Biol. 23:231-244.

38. Jay, H. Distribution of boric acid in nature. Compt. Rend. Acad. Sci. 121:896-899, No. 24.

39. Johnson, E. S., and Dore, W. H. Relation of boron to growth of the tomato plant. Science 67: 324-325, No. 1734.

40. Lebedev, S. I. Utilization of the nitrogen of nodule bacteria by hemp. Dokl. AKad. S.-Kh. Nauk. No. 11, pp. 33-37.

41. Lorenz, A. O. Relation between calcium and boron in growth of garden beet. Prac. Amer. Hort. Soc. 39:668.

42. Lowenhaupt, B. Nutritional effects of boron on growth and development of sunflower. Bot. Gaz. 104:316-322.

43. Maze, P. Influences respectives des elementes de la solution minerale sur le developpement du mais. Ann. Inst. Pasteur 28:21-68, Illus.

44. Midgley, A. R., and Dunkler, D. E. The cause and nature of overliming injury. Vt. Agr. Expl Sta. Bull. 460.

45. Naftel, J. A. Soil liming investigations: V The relation of boron deficiency to over-liming injury. Amer. Soc. Agron. Jour.29:761-771, illus.

46. Orent-Keiles, E. Role of boron in the diet of the rat: Soc. Exp. Biol. and Med. Proc. 44:199-202, No. 1.

47. Owen, E. C. Excretion of borate by the dairy cow. J. Dairy Res. 13:243-248.

48. Piland, J. R., and Ireland, C. E. Application of borac produces seed set in alfalfa. Amer. Soc. Agron. Jour. 33:398.

49. Piland, J. R., Ireland, C. F., and Reisenauer, H. M. Importance of borax in legume seed production in the south. Soil Sc. 57:75-84.

50. Powers, W. L. Boron as a fertilizer for Western Oregon soils. Science 90:36-37.

51. Powers, W. L., and Bouquet, A. G. B. Use of boron in controlling canker of table beets. Ore. Sta. Circ. Inform. 195.

52. Powers, W. L. Use of minor elements in relation to fertility of Oregon Soils. Proc. Oreg. Acad. Sci. (in press).

53. Reeve, E., and Shive, J. W. Potassium-boron relations in plants. Better Crops with Plant Food 27:14-16 and 45-48, No. 4.

54. ---------- and ----------- Potassium-boron and calcium-boron relationships in plant nutrition. Soil Sc. 57:1-14.

55. Sanders, K. B. Nitrogen and ash content of plants: borax fertilization of legumes. Tenn. Agr. Exp. Sta. 56th Ann. Rpt. p. 70.

56. Schaller, W. T. Borate minerals of the Kramer District, Mojave Desert, Calif. U. S. G. S. Prof. Paper 158:137-170, illus.

57. Scharrer, K., and Schreiber, R. Effect of various potassium salts in presence of boron and magnesium on growth of corn in pots. Bodenkunde und Pflanzernahr 26:129-136.

58. Schmucker, T. The influence of boric acid on plants, especially germinating pollen grains. Planta. 23:264-263.

59. Schuster, C. E., and Stephenson, R. E. Sunflower as an indicator plant of boron deficiency in soils. J. Am. Soc. Agron. 32:607-621.

60. Teresi, J. D., Hove, E., Elvehjem, C. A., and Hart, E. B. Boron in the nutrition of the rat. Amer. J. of Physiol. 140:513-518.

61. Tyner, L. E. Effect of media composition on the numbers of bacterial and fungal colonies developing on petri plates. Soil Sc. 57:271-274.

62. Warrington, K. Studies in Absorption of calcium from nutrient solutions with special reference to presence or absence of boron. Ann. Bot. 48: 743-776.

63. Wittstein, A., and Apoiger, F. Entdeckung der Borsäure im Pflanzenreiche. Ann der Chem. und. Pharm. 103:362-364.

64. Woodbridge, V. G. The boron content of some Okanagan soils. Sci. Agr. 20:257-265.

65. Wright, C. H. Soil Analysis, Physical and Chemical Methods p. 265, Second Edition, Thomas Murby and Company, London.

APPENDIX

AVAILABLE BORON IN OREGON SOIL GROUPS AND TYPES

LOCATION	POSITION	SOIL GROUP AND TYPE	DEPTH inches	AVAIL. BORON. ppm.
Western Oregon				
1 mi S. of Astoria Clatsop Co.	Residual	Astoria L.	0-8	0.40
			8-20	0.60
Warren, Columbia Co.	"	Cascade SiL	0-8	0.65
Trenholm, Columbia Co.	"	Aiken SiL	0-8	0.35
Mist	"	Holcomb CL	0-8	0.20
Necanicum, Clatsop Co.	"	Carlton SiL	0-8	0.40
Edy's Farm, Lacomb Linn Co.	"	Olympic CL	0-6	1.2
			6-12	1.0
Yagelski's Farm, Jefferson, Marion Co.	"	Melbourne CL	0-6	1.2
			6-12	1.0
Oregon Sta. Irrigation Plots	O.V.F.	Willamette SiCl	0-7	0.30
			7-20	0.45
			20-40	0.45
Berger Farm	"	"	0-7	0.45
			7-20	0.35
			20-40	0.38
			40-50	0.30
Haag Bros. Farm Reedville, Wash. Co.	"	"	0-7	0.65
			7-20	0.40
			20-40	0.40
			40-50	0.35

Tweed Farm, N.E. of Salem, Marion Co.	O.V.F.	Willamette L	0-7	0.40
Davis Farm, Suver Polk Co.	"	Amity SiCL	0-7	0.50
			7-20	0.40
			20-40	0.45
			40-50	0.35
Belton Farm, New Era, Clack. Co.	"	Willamette SiL	0-7	0.25
			7-18	0.30
			18-36	0.30
1 mi W. of St.Helens Columbia Co.	"	Willamette SiL	0-8	0.40
1 mi N of St Helens, Columbia Co.	"	Willamette L	0-8	0.35
Nibblers Farm, Woodburn, Marion Co.	"	Amity SiL	0-6	0.50
			6-12	0.40
Sand Ridge	"	Salkum CL	0-7	0.35
			7-18	0.35
Peterson Butte	"	Salkum CL	0-6	0.40
Fritz Farm, Gresham, Mult. Co.	"	Powell SiL	0-6	0.50
			6-12	0.70
Chas. Edwards Farm, T 9 S, R 4 W, Sec. 36, Marion Co.	"	Chehalis L	0-8	0.40
John Craig Farm, T 9 S, R 4 W, Sec. 23, Marion Co.	"	Chehalis CL	0-8	0.40
Nusem Farm, Clatskanie, Columbia Co.	Recent	Clatskanie Muck	0-6	0.15
			6-12	0.20
Scappoose, Columbia Co.	"	Sauvie L	0-8	0.45
Veronica, Columbia Co.	"	Wapato SiCL	0-8	0.65

1 mi W of Veronica	Recent	Nehalem SiL	0-8	0.45
6 mi N of Seaside Clatsop Co.	"	Geathart F m SaL	0-8	0.35
			8-11	0.50
			11-17	0.50
Warrenton Clatsop Co.	"	Warrenton LFSa	0-8	0.60
			8-11	0.40
			11-16	0.40
1 mi S of Westport Clatsop Co.	"	Westport FSa	0-8	0.30
			8-12	0.50
			12-16	0.60

Eastern Oregon

7 mi E of Mitchell, Wheeler Co.	Residual	Waha L	0-10	0.80
½ mi SW of Cabbage Hill School	"	Underwood SiL	0-8	0.45
2½ mi SE of Basket Mt. School	"	Helmer VFSaL	0-8	0.40
			8-18	0.50
1 mi W of Redmond, Deschutes Co.	O.V.F.	Deschutes SaL	0-8	0.40
			8-24	0.40
½ mi W of Terrebonne, Deschutes Co.	"	Terrebonne SaL	0-12	0.80
			12-244	0.60
Redmond, Deschutes Co.	"	Redmond SaL	0-12	0.50
Redmond, Deschutes Co.	"	Milwaukee Muck	0-12	0.30
½ mi NW of Culver, Jefferson Co.	"	Madras SaL	0-12	0.60
1 mi E of Culver, Jefferson Co.	"	Era L	0-12	0.60
Sires Farm	"	Sisters L	0-10	0.80

1 mi E of Iowa School, Union Co	O.V.F	Alicel L	0-7 7-24	0.80 0.85
Lagrande, Union Co	"	Springdale SaL	0-8	0.80
Lagrande, Union Co	"	Lagrande SiCL	0-7 7-24	0.65 0.75
Cove, Union Co.	"	Hyrum stony C	o-7 7-24	0.90 0.80
3½ mi SE of Lagrande, Union Co	"	Gooch SiCL	0-7 7-18	1.55 1.50
3/4 mi E of Iowa School, Union Co	"	Gooch SiL	0-7 7-18	1.40 1.40
4 mi SW of Summerville, Union Co.	"	Conley SiCL	0-7 7-20	0.80 0.85
Sec. 27, T 35, R 39 E, Union Co.	"	Klamath SiCL	0-7 7-24	1.10 1.30
¼ mi W of Summerville, Union Co.	"	Catherine SiL	0-7 7-24	0.80 0.95
Sec. 19, T 8 S, R 40 E, Baker Co.	"	Hamas SiL	0-3 3-10 10-20	0.75 0.75 0.70
Sec. 10, T 9 S, R 40 E, Baker Co.	"	Bardock SiL	0-8 8-30	0.80 0.75
Sec. 11, T 9 S, R 40 E, Baker Co.	"	Baker L	0-15 15-30 30-38	0.75 0.80 0.75
Sec. 10, T 9 S, R 39 E, Baker Co.	"	Hibbard SiL	0-10 10-15	0.80 0.80
Sec. 34, T 8 S, R 39 E, Baker Co.	"	Wingville SiL	0-10	0.90
Keating, Baker Co.	"	Keating CL	0-10	0.80

4 mi NE of Lawen, Harney Co.	O.V.F.	Fiander C	0-4	1.0
			4-12	1.8
			12-24	2.0
Grange Hall, Burns Harney Co.	"	Umapine C	0-3	11.8
			3-14	2.5
			14-30	2.5
¼ mi NE of Burns, Harney Co.	"	Wingville SiL	0-8	0.90
			8-16	1.50
			16-26	1.0
Harney Co.	"	Klamath Peaty SiL	0-12	0.80
			12-24	0.80
			24-36	0.90
Indian Colony, Harney Co	"	Catherine C	0-8	0.70
			8-20	0.70
			20-42	0.60
Belle A Ranch	"	Silvies L	0-10	0.65
			10-20	0.60
Haney Lane, S. of Burns, Haney Co	"	Gooche C	2 -12	0.90
			12-26	1.0
Langell Valley Klamath Co	"	Gooch SiCL	0-12	1.0
			12-24	1.0
			24-36	1.0
			36-60	1.0
			60-72	1.5
Tulana Farms, 1st cross dyke, Klamath Co	"	Klamath CL	0-7	0.85
			7-20	0.90
			20-33	1.0
Tulana Farms, 2nd c ross dyke, Klamath Co	"	Klamath Peat	0-7	0.45
			7-18	0.40
			18-37	0.40
Tulana Farms, 5th cross dyke road Klamath County	"	Klamath Peat	0-7	0.45
			7-18	0.50
			18-37	0.50
Tulana Farms, ½ mi E of main ditch Klamath County	"	Klamath peat	0-7	0.65
			7-18	0.50
			18-30	0.50

Tulana Farms, 1½ mi E of main ditch, Klamath Co	O.V.F.	Klamath Peat	0-7 7-	0.60
Tulana Farms, 2½ mi E of main ditch, Klamath Co	"	"	0-7 7-24 24-30	0.90 0.85 0.85
Scott Warren, Algoma, Klamath Co	"	"	0-8 8-20 20-40	0.15 0.10 0.10
5 mi E of Hatfield on California side Klamath Co	"	Hatfield SiL	0-7 7-20 20-33	0.80 0.85 0.85
6 mi E of Hatfield on California side Klamath Co	"	"	0-8 8-20 20-40	0.85 0.80 0.75
Sec. 33, T 1 N, R 32 E, Umatilla Co	Recent	Pilot Rock SiL	0-8	0.45
7 mi S of Pendleton Umatilla Co	"	McKay SiL	0-8	0.55
1 mi S of Hermiston Umatilla Co	"	Ephrata FSaL	0-8 8-21	0.75 0.80
2½ mi NE of Stanfield Umatilla Co	"	"	0-8	0.70
Freewater, Umatilla Co	"	Stanfield L	0-10 10-20 20-36	0.50 0.60 0.60
Milton, Umatilla Co	"	Yakima SiL	0-8	0.80
2½ mi W of Stanfield Umatilla Co	"	Meadows SiL	0-8	0.65
7½ mi S of Echo Umatilla Co	"	Stanfield VFSaL	0-8	0.45
Pendleton, Umatilla Co	Eolian	Ritzville SaL	0-10	1.20

3¼ mi N of Hermiston Umatilla Co	Eolian	Rupert LSa	0-8	0.60
¼ mi NE of Saxe Umatilla Co	"	Adams VFSaL	0-8	0.70
1½ mi SW of Athena Umatilla Co	"	Adams SiL	0-8 8-16	0.75 0.80
3 mi NE of Nolin Umatilla Co	"	Ritzville SiL	0-8	0.60
1½ mi E of Athena Umatilla Co	"	Athena SiL	0-16	0.75
1 mi N of Myrick Umatilla Co	"	Walla Walla SiL	0-8	0.80
1 mi N of Holdman Umatilla Co	"	Walla Walla VFSaL	0-8	0.75
	"	Alicel L	0-7 7-24	0.80 0.85
Crabtree Farm, Wasco Co., Sec. 23, T 4 S R 13 E	"	Condon L	0-10	0.80
Olds Farm, Sec. 6 T 5 S, R 12 E Wasco Co	"	Wamic L	0-10	0.70
Corum Farm, Sec. 24, T 28 S, R 14 E, Lake Co	Unclassified		0-10 10-17	0.60 0.65
Perry Farm, Sec. 26, T 38 S, R 19 E, Lake Co	"		0-7 7-16	0.70 0.75
Travis Farm, Sec. 17, T 40 S, R 19 E, Lake Co	"		0-7 7-14	0.70 0.70
Warner Valley, Sec. 14, T 38 S, R 24 E, Lake Co	"		0-12 12-18 18-36	0.80 0.80 0.90
Warner Valley, Sec. 10 T 36 S, R 24 E, Lake Co	"		0-12	0.90

Alkali Land, Prineville, Crook Co	Unclassified		0-12	0.95
½ mi S of Malheur Station, Malheur Co	"		0-12	0.75
McCarty Farm, 5 mi SW of Ontario, Mahleur Co	"		0-10	0.80
			10-27	0.85
MCCarty Farm, Upper bench Malheur Co	"		0-18	0.80
			18-24	0.85
Mallet Farm, between Ontario and Vale, 1881 Waterright, Malheur Co	"		0-8	0.75
			8-20	0.75
			20-36	0.80
Mallet Farm, Sagebrush land, Malheur Co	"		0-8	0.90
			8-20	0.85
			20-36	0.85
Earl Weaver, Ontario, Malheur Co	"		0-10	0.70
			10-20	0.75
			20-36	0.80
Airport, Ontario Malheur Co	"		0-10	0.80
			10-20	0.80
			20-36	0.90
Mitchell Farm N of Mitchell Butte, Owyhee Malheur Co	"		0-8	0.70
Vale Check Plots Malheur Co	"		0-6	0.90
			6-20	0.95
			20-40	1.00
Bully Creek, 17 mi " W of Harper	"		0-7	0.90
			7-18	1.50
			18-30	1.50

<u>Southern</u> <u>Oregon</u>

Sec. 31, T 34 S, R 5 W, Josephine Co	Residual	Aiken CL	0-12	0.50
			12-36	0.40

Sec. 16, T 36 S, R 5 W, Josephine Co	Residual	Olympic L	0-12	0.65
			12-36	0.60
Sec. 10, T 34 S, R 6 W, Josephine Co	"	Hugo L	0-10	0.55
			10-36	0.50
Sec. 36, T 36 S, R 6 W, Josephine Co	"	Holland SaL	0-12	0.60
			12-36	0.65
Sec. 14, T 35 S, R 6 W, Josephine Co	"	Siskiyou SaL	0-12	0.45
			12-36	0.45
Sec. 1, T 36 S, R 7 W, Josephine Co	"	Sites GrCL	0-12	0.75
			12-36	0.60
Sec. 3, T 34 S, R 6 W Josephine Co	"	Sites CL	0-12	0.60
			12-36	0.50
Sunnyhill School Josephine Co.	"	Riverton L	0-7	0.20
			7-18	0.20
			18-36	0.25
Sec. 30, T 36 S, R 6 W, Josephine Co	O.V.F.	Jerome FSaL	0-12	0.40
			12-36	0.40
Sec. 27, T 36 S, R 6 W, Josephine Co	"	Barron SaL	0-12	0.25
			12-36	0.30
Talent Exp Sta. Jackson Co	"	Agate CL	0-10	0.35
			10-30	0.40
Cote Orchard, Medford, Josephine Co	"	Coker C	0-6	0.25
N end Roseburg Fairgrounds, Douglas Co	"	Cove C	0-8	0.50
Sec. 35, T 30 S, R 7 W Douglas Co	"	Kerby CL	0-12	0.50
			12-36	0.50
Wilbur, Douglas Co	"	Dayton SiL (dark surface)	0-8	0.35
Plantation Inn, N of Dillars Douglas Co	Residual	Melbourne SiL	0-12	0.40
			12-24	0.45
			31-41	0.45

Ford, Garden Valley Douglas Co	Recent	Roseburg SiL	0-12	0.50
			12-24	0.50
			24-36	0.60
Moyers Nursery Douglas County	"	Umpqua SiL	0-12	0.35
			12-24	0.40
			24-36	0.40
2 mi S Yoncalla Douglas County	Residual	Melbourne SiL	0-6	0.40
			6-14	0.40
Lighthouse, Coos Co	Recent	Empire LSa	0-7	0.15
			7-15	0.10
1 mi E of Bandon Coos Co	"	Empire CL	0-7	0.20
			7-15	0.20
			24-40	0.15
1 mi W of Coquille Coos Co	"	Coquille SiCL	0-7	0.15
			7-18	0.10
			18-40	0.10
Sec. 16, T 36 S, R 6 W, Josephine Co	"	Columbia L	0-12	0.45
			12-36	0.40
½ mi W of Grants Pass, Josephine Co	"	Columbia GrSaL	0-12	0.50
6 mi N of Florence Lake Co	"	Blacklock L	0-5	0.20
			5-15	0.20
			15-18	0.10