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/E. Hugh Gardner

Several crops grown in the Willamette valley of western Oregon
respond to applications of boron fertilizers. The acid, highly-leached
soils of this area are naturally low in plant-available B. Application
of B to the soil annually or at less frequent intervals is currently
recommended, but the fate of applied B and the residual effect on plant
growth has received little attention.

In studying boron in these soils a more convenient and more accu-
rate method for determining hot-water-soluble B based on the azomethine-H
procedure was developed and adopted to replace the curcumin method.
Substitution of 0.02 $\underline{M}$ $CaCl_2$ for distilled water for extraction of soil
B resulted in clear, colorless solutions which permitted accurate
colorimetric determination of B.

A greenhouse experiment was established to investigate 1) the
influence of soil properties on the mobility and plant-availability of
B, 2) the magnitude of the loss of B from the surface soil by leaching,
and 3) the residual effect of applied B on plant growth and the B
supplying power of soils. Soil samples from sixteen locations represent-
ing five agriculturally important soil series were studied. The

percentage of B from a 2.0 mg B/kg application recovered in 25 cm of leachate decreased as soil organic matter, clay, and free iron and aluminum oxide content increased. The results clearly indicated the importance of organic matter in reducing the mobility of B, and suggested that free Fe and Al oxides, and perhaps clay, may also be important. Soil acidity over a pH range of 5.4 to 7.5 did not influence the mobility of B.

Dry matter yields for three cuttings of New Zealand white clover (Trifolium repens L.) were not significantly affected by B soil test level or B applied at planting. Plant tissue concentrations of B were high compared to field-grown forage legumes and, while these concentrations were affected by extractable soil B level or B application, the correlations between soil test level of B and plant content of B were low.

A balance-sheet approach, where the amounts of leachate, plant, and extractable soil B were tabulated, indicated a B supplying power for the soils studied. All sixteen soils released B to leaching and cropping with minimal decreases in hot-water-soluble B content. When B was applied to the soils, only those higher in organic matter and/or free Fe and Al oxides tended to "fix" B in a form not recoverable by leaching, cropping and hot-water extraction. The capacity of the soils to maintain soluble B levels under cropping depended both on the individual soil and the amount of B present (i.e., check vs. B applied). The results are in agreement with a small body of literature suggesting the importance of intensity/capacity relationships in the availability of B to plants.

The Mobility and Plant Availability of
Boron in Selected Western Oregon Soils

by

David R. Parker

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INTRODUCTION

The Willamette valley of northwestern Oregon is an agricultural
area with a wide diversity of crops and soils. The climate is Mediter-
ranean; of the 100 to 150 cm of annual rainfall about 70% falls between
November and March, with less than 5% occurring between June and August
(Knezevich, 1975). Soils vary in age and parent material and include
soils formed in recent alluvium, Late Pleistocene epoch terrace sedi-
ments, and older residuum/colluvium derived from sedimentary and igneous
rocks (Knezevich, 1975). The soils are neutral to very acidic and many
are highly leached. Older soils have well-developed B horizons while
all soils tend to have A horizons with relatively high organic matter
contents.

Crops grown in this area include grass seed, small grains, pasture
and hay crops, and a wide variety of horticultural and specialty crops.
Many of these crops are known to respond to applications of boron fer-
tilizers. Members of the Leguminoseae, Umbelliferae, Chenopdiaceae,
Cruciferae, and Rosaceae families are particularly responsive to B
applications, while the monocots are generally unresponsive to B (Mengel
and Kirkby, 1978).

Powers (1939) first reported responses to B fertilizers for several
crops in western Oregon, including alfalfa (Medicago sativa L.), beets
(Beta vulgaris L.), and celery (Apium graveolens L.). Applications of
B reduced stem-crack in celery and canker in beets, and often increased

yields of alfalfa. He also noted that sandy, well-leached soils were more likely to be boron-deficient and that reapplication of B every two to three years was required for optimal growth of alfalfa. Dregne and Powers (1942) further explored factors leading to B deficiencies in western Oregon and noted that liming, soil moisture content, and soil organic matter content may influence boron availability. Mack et al. (1960) found that, after one winter's rainfall, most of the B applied at 2 to 32 lbs B/A could not be recovered from the surface 12 inches of two Willamette valley soils using hot-water extraction (Berger and Truog, 1940). It would appear that B is fairly mobile in the acid, well-leached soils of western Oregon but that the mobility may vary between soils with differing properties.

Generally, the differences in mobility of B under leaching condi-tions for various soils have been attributed to differences in soil texture with sandy soils being less retentive of B than finer-textured soils (Kubota et al., 1948; Reeve et al., 1944; Wilson et al., 1951). Other factors such as organic matter content, iron and aluminum oxide content, and pH of soils have received little attention regarding their relationship to the leachability of boron. Some laboratory adsorption studies have indicated that soil properties other than texture are im-portant, but have not directly correlated the adsorption of B with the mobility of B (Olson and Berger, 1947; Sims and Bingham, 1968).

Over the years, the use of B fertilizers in Oregon has increased. In 1980, over 1000 tons of B fertilizer materials were sold in Oregon (Oregon Department of Agriculture, 1980), the vast majority being used west of the Cascade mountains. The fate of applied B, and the soil

properties controlling the mobility and plant-availability of B, were
the subject of this study. The objectives were to:

1. Identify which soil properties control or influence the
    mobility and plant-availability of boron.

2. Estimate what fraction of applied B is leached out of the
    surface soil.

3. Examine the residual effects of applied B on plant growth
    and the B supplying power of soils.

A secondary objective of this research was to develop a more pre-
cise and convenient procedure for determining the hot-water-soluble B
content of soils. Boron analysis using azomethine-H (Wolf, 1971) was
investigated and chosen as the basis of a procedure to replace the older
curcumin method of Dible et al. (1954). Details of the azomethine-H
procedure are presented in Chapter 1, which is a manuscript to be
submitted to Communications in Soil Science and Plant Analysis. The
results of the greenhouse investigation of B mobility and plant-
availability are presented in Chapter 2, which will be submitted to
the Soil Science Society of America Journal.

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CHAPTER ONE

THE DETERMINATION OF HOT-WATER-SOLUBLE BORON IN SOME
ACID OREGON SOILS USING A MODIFIED AZOMETHINE-H PROCEDURE

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ABSTRACT

A method is proposed for determination of hot-water-soluble boron in acid soils from western Oregon. The soil sample is boiled in 0.02 M $CaCl_2$, filtered, and boron determined using azomethine-H. Soils extracted in this way yielded extracts with little color in them and the predicted error due to this color was 0.00-0.07 ppm B. The use of charcoal as a decolorizing agent resulted in comparatively high predicted errors.

Inductively-coupled plasma emission spectroscopic (ICP) analysis of distilled water and 0.02 M $CaCl_2$ extracts indicated that the extractable B level was not affected by the presence of $CaCl_2$. Azomethine-H yielded comparable values to ICP but the curcumin method tended to give high values for hot-water-soluble B.

INTRODUCTION

Since its introduction the azomethine-H reagent (Shanina et al., 1967) has rapidly gained favor as a method for determining boron in plant materials, soil extracts and water (Wolf, 1971, 1974; Gupta, 1979; John et al., 1975). This method has several advantages over other procedures such as carmine (Hatcher and Wilcox, 1950), quinalizarin (Berger and Truog, 1939), and curcumin (Dible et al., 1954). The azomethine-H procedure is simple, rapid, does not require the use of concentrated acids, and is subject to few interferences.

The major drawback to the azomethine-H method for soils is error resulting from suspended or dissolved material which imparts a yellow color to the extract. A significant positive error can occur during the colorimetric reading of the yellow boron-azomethine-H complex. Gupta (1979) and Wolf (1974) have proposed the use of charcoal to decolorize soil extracts. However, both warn that adding excess charcoal can lead to a loss of boron from solution and a low value for extractable B. Moreover, Gupta (1979) found that the amount of charcoal necessary to decolorize a soil extract was roughly proportional to the organic matter content of the soil, and that the amount of charcoal added should be adjusted accordingly. This represents a potentially large inconvenience when analyzing a large number of soil samples.

Dible et al. (1954) recommended the addition of 0.02 g $CaCl_2 \cdot 2H_2O$ to the soil extract after boiling to flocculate the colloids prior to centrifugation or filtering. Baker (1964) extracted soils in a 0.007 M $CaCl_2$ solution containing two polyacrylamide flocculating agents. Both these methods were satisfactory for clarifying extracts for B analysis by the curcumin method but specific data on the clarity of the solutions were not given. The curcumin-boron complex is colorimetrically determined at a longer wavelength than the azomethine-H-boron complex, and is less sensitive to yellow color in the extract.

The purpose of this study was to identify a method for obtaining clear, colorless extracts from western Oregon soils for boron determination using azomethine-H. To be useful, the method had to meet three criteria: 1) a clear solution must be obtained, 2) the method should yield results similar to those obtained by boiling with distilled water, and 3) the method should be applicable to routine analysis of a large number of samples.

MATERIALS AND METHODS

Ten soil samples representing eight western Oregon soil series were selected to obtain a range in mineralogy, texture, organic matter content and hot-water-soluble boron (Table 1).

For all B extractions 10.0 g of air dried, 2 mm sieved soil and 20.0 ml extracting solution were boiled for exactly 5 minutes in a 100 ml, low-boron glass boiling flask. A condenser tube attached to the mouth of the flask refluxed the sample. The hot solutions were immediately transferred to filters or 50 ml plastic centrifuge tubes.

Boron was determined by the azomethine-H method of Wolf (1971) with only slight modification. Four ml of sample and one ml of buffer-chelating reagent were added to a 12 ml plastic test tube and vortexed. After adding 1.0 ml of 0.9% azomethine-H solution the tube was again vortexed, allowed to stand for one hour, vortexed again, and the absorbance read at 420 nm using a Bausch and Lomb Spectronic 100 spectrophotometer. Approximately 0.5 ml of Brij-35 (a surfactant available from Alpkem Corporation, Portland, Ore. 97214) per 600 ml buffer-masking agent was included to improve the performance of the aspirating flow cell of the spectrometer.

A series of experiments were performed to 1) develop a method for predicting the error in B analysis by azomethine-H due to color in the soil extract, 2) determine the effect of different extractants on extract clarity and hot-water-soluble B values, and 3) examine the effect of various filtration and centrifugation treatments on extract clarity.

the degree of color in the extracts and the resulting error in the B determinations. Assuming that the absorbances of the colored solutions and the azomethine-H-B complex are additive, the error resulting from color (expressed as ppm B on a soil basis) is equal to this measured absorbance divided by the slope of the absorbance:concentration calibration line for the azomethine-H-B complex (0.44) multiplied by the extracting ratio (2:1).

The ten soils were extracted with double-distilled water, the slurries centrifuged at 15,000 rpm (23,950 x g) for 30 minutes, and the supernatants filtered through Whatman #50 filter paper. The error due to color in these extracts was estimated as described above.

The extracts were analyzed for B by the azomethine-H method and by inductively coupled plasma emission spectroscopy (ICP). For the latter method, an Applied Research Labs Quantometric Analyzer was used with an incident power of 1.6 kW and a wavelength of 2497.7 Å. Other parameters were as per the manufacturer's specifications. Boron analysis by ICP is independent of any color in the extract, permitting a check on the error due to color in azomethine-H B determinations.

The difference between the boron values obtained with azomethine-H and ICP was taken to be the actual error in B and was compared with the predicted error (Table 2). There is a close agreement between the actual and predicted error (Table 2) indicating that the calculation used gave a reasonable estimate of the error due to color in the extract for boron determinations using azomethine-H.

Experiment 2: Effect of extracting solution on extract clarity and hot-water-soluble B values.

The effect of the extractant on the clarity of solution was investigated by extracting the soils with distilled water, 0.02 M $CaCl_2$, and distilled water plus 0.3 g charcoal. The

slurries were centrifuged at 15,000 rpm and the supernatants filtered. The absorbance of the filtrates was measured and the predicted error in B was calculated as previously described.

TABLE 2

Comparison of Predicted Error and Actual Error in Boron
Determination Using Azomethine-H and Distilled Water
Extracts

Soil	ICP	Azomethine	Error	Predicted Error
	------------------B, ppm----------------			
Bashaw	0.30	0.46	0.16	0.15
Chehalis	0.62	1.00	0.38	0.33
Dayton	0.20	0.28	0.08	0.05
Jory 1	0.74	0.90	0.16	0.15
Jory 2	0.16	0.18	0.02	0.01
Newberg	0.28	0.66	0.38	0.36
Willakenzie	1.26	1.48	0.22	0.30
Willamette	0.44	0.94	0.50	0.40
Woodburn 1	0.44	0.72	0.26	0.25
Woodburn 2	1.54	1.82	0.28	0.37
Mean	0.60	0.84	0.24	0.24

The predicted error in B for distilled water extracts indicates the possibility of large errors, up to 0.40 ppm (Table 3). Addition of 0.3 g charcoal per 10 g soil reduced this error but was not nearly as effective as extraction with 0.02 M $CaCl_2$. The rate of charcoal used is comparable to the rate of 0.8 g per 25 g soil employed by Gupta (1979), which was effective in decolorizing soils from Nova Scotia containing up to 4.1% organic matter. The ineffectiveness of charcoal in this study may be due to the high clay content of the soils. Gupta (1979) worked almost exclusively with podzolized sandy loams where organic

matter is the primary cause of colored solutions. The use of 0.02 M CaCl$_2$ effectively eliminated the problem of dispersed fine clay in extracts from western Oregon soils.

TABLE 3

Predicted Error in Boron Determination Due to Color in Extract
for Different Extractants

| | Extractant | | |
Soil	H$_2$O	H$_2$O+0.3 g Charcoal	0.02M CaCl$_2$
	----------------B, ppm----------------		
Bashaw	0.15	0.02	0.02
Chehalis	0.33	0.18	0.02
Dayton	0.05	0.02	0.01
Jory 1	0.15	0.10	0.02
Jory 2	0.01	0.00	0.00
Newberg	0.36	0.16	0.02
Willakenzie	0.30	0.13	0.05
Willamette	0.40	0.07	0.05
Woodburn 1	0.25	0.22	0.01
Woodburn 2	0.37	0.04	0.05
Mean	0.24	0.09	0.03

The effect of extractant and method of determination of B was investigated using triplicate samples which were extracted with distilled water and 0.02 M CaCl$_2$. The slurries were centrifuged at 15,000 rpm, the supernatants filtered, and B determined on both extracts by ICP and on the 0.02 M CaCl$_2$ extracts by azomethine-H. A separate, triplicate analysis was made using distilled water extracts and the curcumin method of Dible et al. (1954) as employed by the Oregon State University soil test laboratory (Berg and Gardner, 1978). The curcumin method, still

widely used, was included for comparison with the proposed
method. Analyses of variance were used to test the data for
significant differences between methods.

Distilled water and 0.02 M $CaCl_2$ extracts analyzed by ICP
yielded no significant differences (p=0.05) in extractable B
values (Table 4). As mentioned above, boron analysis by ICP is
a good means of comparing different extracts because it is insen-
sitive to any color in the extracts. These results indicate that
the substitution of 0.02 M $CaCl_2$ for distilled water did not lead
to different values for hot-water-extractable B.

TABLE 4

Hot-water-Soluble Boron Values Using Four Methods.
Values are Means of Three Determinations.

Soil	ICP		Azomethine-H	Curcumin
	H_2O	$CaCl_2$	$CaCl_2$	H_2O
	---------------B, ppm---------------------			
Bashaw	0.23	0.25	0.40	0.44
Chehalis	0.65	0.65	0.66	0.62
Dayton	0.15	0.15	0.19	0.28
Jory 1	0.81	0.90	0.93	1.01
Jory 2	0.15	0.22	0.25	0.31
Newberg	0.25	0.21	0.27	0.30
Willakenzie	1.25	1.27	1.23	1.60
Willamette	0.45	0.42	0.59	0.55
Woodburn 1	0.41	0.37	0.41	0.56
Woodburn 2	1.58	1.53	1.50	1.63
Mean	0.59	0.60	0.64	0.73
$s_{\bar{x}}$	0.06	0.09	0.07	0.10
C.V.,%	10.1	14.4	10.8	13.4

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The azomethine-H method using 0.02 M $CaCl_2$ extracts yielded slightly higher B values than ICP in most cases (Table 4). The mean difference was not statistically significant at the 0.05 level of probability. Differences were small except for the Bashaw and Willamette soils where the azomethine-H values were somewhat higher. The coefficient of variation for triplicate determinations was 10.8% for the azomethine-H method as compared with 10.1% and 14.4% for ICP on distilled water and 0.02 M $CaCl_2$ extracts, respectively.

The curcumin method yielded the highest B values for eight of the ten soils and the mean was significantly higher than that for the other methods (Table 4). The extracts were not decolorized for the curcumin analysis and the positive error could be partly due to turbidity in the extracts.

Azomethine-H has advantages over the curcumin method in that the evaporation, redissolution, and filtration steps of the curcumin method are eliminated. Also the azomethine-H-boron complex is stable for up to 4 hours giving the analyst more flexibility in the colorimeter readings than with the curcumin method. Lastly, high nitrate levels and variation in salt content which lead to errors in the curcumin determination of boron (Williams and Vlamis, 1970; Wolf, 1971) are not a source of error when using azomethine-H (Wolf, 1971; John et al., 1975).

Experiment 3: Effect of centrifugation and/or filtration on clarity of 0.2 M $CaCl_2$ extracts.

The effect of centrifugation speed and/or filtration on the clarity of extracts was studied by centrifuging 0.02 M $CaCl_2$ extracts at 6000, 9000 and 15,000 rpm (4140, 9340 and 23,950 x g at the bottom of the tube, respectively). Additional treatments included filtration alone and centrifuging at 9000 and 15,000 rpm followed by filtering the supernatant. Whatman #50 filter paper

was used for filtrations. The potential error in B determination by azomethine-H was calculated as in Experiment 1.

The clearest $CaCl_2$ extracts were obtained by centrifuging at 9000 or 15,000 rpm and filtering the supernatant although comparable results were obtained with centrifugation at 15,000 rpm alone or filtration alone (Table 5). Filtering the extracts without centrifugation would be a time-saving method where many samples are to be analyzed and a slight loss of accuracy, as with the Willamette and Woodburn 1 soils, can be afforded. Filtration improved the clarity of some centrifuged samples by removing organic matter which floated in the supernatant. Pipetting aliquots from centrifuged, non-filtered samples was complicated by having to avoid large particles of floating organic material. In short, it appears that centrifugation is not necessary, but that filtration is necessary to obtain usable, clear soil extracts.

TABLE 5

Predicted Error in Boron Determination Due to Color in Extract for 0.02 M $CaCl_2$ Extracts Centrifuged at Various Speeds and/or Filtered

Soil	rpm 6000	9000	15000	Filtered	9000 rpm & Filtered	15000 rpm & Filtered
				B ppm		
Bashaw	0.11	0.04	0.02	0.02	0.02	0.02
Chehalis	0.29	0.11	0.01	0.01	0.02	0.02
Dayton	0.07	0.02	0.01	0.01	0.01	0.01
Jory 1	0.15	0.02	0.01	0.02	0.02	0.02
Jory 2	0.06	0.01	0.01	0.00	0.00	0.00
Newberg	0.06	0.02	0.02	0.02	0.02	0.02
Willakenzie	0.63	0.19	0.06	0.05	0.05	0.05
Willamette	0.16	0.09	0.09	0.07	0.05	0.05
Woodburn 1	0.23	0.01	0.02	0.06	0.01	0.01
Woodburn 2	0.47	0.14	0.05	0.04	0.05	0.05
Mean	0.223	0.065	0.030	0.030	0.025	0.025

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It was also noted that samples extracted with distilled water plus 0.3 g charcoal, when filtered only, yielded extremely turbid solutions which were unusable for colorimetric B analysis. Thus, the centrifugation step could not be eliminated if charcoal were used to decolorize extracts from these soils.

CONCLUSIONS

The substitution of 0.02 M $CaCl_2$ for distilled water is an effective means of obtaining clear hot-water extracts for boron analysis from selected western Oregon soils. The maximum predicted error in B was 0.05 ppm for samples centrifuged at 15,000 rpm and filtered and 0.07 ppm for samples only filtered. Filtration alone yielded solutions of adequate clarity for most applications, including soil testing programs.

The presence of $CaCl_2$ in the extracting solution does not alter the amount of boron extracted. Analysis of 0.02 M $CaCl_2$ extracts using azomethine-H yielded hot-water-soluble boron values comparable to those obtained by ICP.

The use of charcoal as a decolorizing agent is not recommended due to the greater clarity of solutions obtained with 0.02 M $CaCl_2$ and the potential for negative error in boron analysis when charcoal is used.

The method outlined here, where the soil sample is boiled in 0.02 M $CaCl_2$, filtered and the filtrate assayed for B directly using the azomethine-H reagent provides a simple, rapid and accurate means for determining hot-water-soluble boron in western Oregon soils.

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CHAPTER TWO

FACTORS AFFECTING THE MOBILITY AND PLANT AVAILABILITY

OF BORON IN SOME WESTERN OREGON SOILS[1]

D. R. Parker and E. H. Gardner[2]

ABSTRACT

Surface soil from five diverse soil series was used to investigate the influence of soil properties and constituents on the mobility of boron in a greenhouse study. From 13 to 61% of a 2.0 mg/kg surface application of B was recovered in 25 cm of leachate. Recovery of B decreased with increased soil organic matter, clay, and free Fe and Al oxide content but statistical separation of the effects of individual components was complicated by intercorrelations among these soil properties. No effect of soil pH on B mobility over a range of 5.4 to 7.5 was observed.

Following leaching, the soils were cropped with New Zealand white clover (Trifolium repens L.). Yield differences were not correlated with hot-water-extractable B levels ranging from 0.47 to 2.34 µg/g or with B applied at planting. Plant B concentrations were high ranging

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from 60 to 150 µg/g. As the range in hot-water-soluble B values encompassed current concepts of deficiency levels in western Oregon soils, the merits of investigating soil B critical levels under greenhouse conditions are questioned.

A balance sheet approach indicated that soils have reserves of leachable and plant-available B not detected in the conventional hot-water extraction. The B-supplying power of these soils varied both within and among soil series and depended on soil properties and the amount of B in the soil system.

Boron deficiencies have been observed in a wide variety of crops in the Willamette Valley of western Oregon. Low native levels of plant available B combined with an acidic, highly-leached soil environment are thought to be contributing factors. Concern has also been expressed over the residual effect of high rates of application of fertilizer B on boron-sensitive crops such as snap beans. The mobility of boron in soils has not been exhaustively studied. Kubota et al. (17) found that applied boron was retained near the surface of finer-textured soils but was not retained by sandy soils. This study did not take into account the effect of soil properties such as pH and organic matter content. Other studies which emphasized the effect of soil texture on B mobility have likewise largely ignored the role of other soil properties (5, 23, 27). Lime applications have been shown to retard downward movement of B into the soil profile (2, 17).

Indirect evidence for the role of various soil constituents in controlling B mobility has been provided by laboratory adsorption studies. Sims and Bingham (24) concluded that iron and aluminum, present as interlayer materials, coatings, or impurities, were responsible for B retention by layer silicates. They also found that retention of B by soils was most highly correlated with free iron oxide content and, to a lesser degree, with extractable aluminum (25). No correlation between B retention and soil organic matter content was found. However, other workers have shown that organic matter may be important in adsorption of boron by soil (21, 22). Interpretations based on these types of studies must be made with caution due to the high equilibrium concentrations of B usually employed--often ten to several hundred mg B/liter. Such

conditions cannot be safely interpolated to acid soil conditions where soil solution B concentrations are often 0.5 mg/liter or less.

Soil properties such as texture, pH, and organic matter content have also been shown to influence the plant-availability of B. Martens (18) found that B uptake by corn was best predicted by a multiple regression equation taking into account hot-water-soluble B, pH, % organic matter and % clay, with all variables but clay showing a positive correlation. John et al. (14) found that B concentrations in corn and spinach were greater in high organic matter soils where soil B levels were low, but that organic matter depressed plant B levels where B had been applied at high rates. They also associated decreased plant B levels with the higher free Fe and Al oxide contents of a highly weathered soil as compared to a recent alluvial soil. Wear and Patterson (26) showed that the B content of greenhouse-grown alfalfa decreased with increasing soil pH and clay content. Jones and Scarseth (16) attributed lime-induced B deficiency to high levels of soil Ca, although Gupta and McLeod (12) concluded that increases in soil pH alone were responsible.

Several papers have reported that boron deficiencies occur during periods of moisture stress (2, 8, 9, 13). It has been postulated that surface horizons contain adequate plant-available B, probably as organically combined B, but that as the subsoil becomes nutritionally more important during drought, B deficiency is more prevalent (2, 8, 13). Baker and Mortensen (2) related B deficiencies in alfalfa to low extractable B levels in the 25 to 41 cm layer of soil.

The hot-water-soluble boron soil test of Berger and Truog (4) is commonly used as an index of plant available B. However, low correlations between this test and B concentrations in plants have been noted

(6, 18). Several workers postulated a soil B-supplying power not re-
flected in the hot water extraction (1, 2, 6). Colwell (6) proposed a
biological test for available B using sunflowers wherein a high B demand
is placed on the soil. Baird and Dawson (1) showed that a six-hour
soxhlet extraction removed an additional reserve of plant-available B,
although correlations between hot-water-soluble B and plant B, and
soxhlet-extractable B and plant B were comparable.

The objectives of this study were: 1) to evaluate what soil prop-
erties influence or control the mobility and plant availability of B in
the surface horizon of Willamette Valley soils, 2) to estimate what
fraction of applied B is lost through leaching and the residual effect
on plant growth, and 3) to evaluate the release of "native" boron in
these soils during leaching and cropping.

MATERIALS AND METHODS

Soil Collection and Characterization

Bulk soil samples were collected from the surface 15 cm of 24 western Oregon field locations representing five agriculturally important soil series. These soils were air-dried, passed through a 2 cm screen, and thoroughly mixed. After preliminary analyses, 16 soil samples were selected to obtain a range in extractable boron, pH, clay content and organic matter content (Table 1).

Mechanically-ground, 2 mm-sieved samples were analyzed for P, K, Mg, Ca, pH, CEC and % organic matter according to the methods reported by Berg and Gardner (3). Hot-water-soluble boron was determined in triplicate by boiling 10.0 g of soil in 20.0 ml of 0.02 M $CaCl_2$ for 5 minutes, filtering, and analyzing the clear extract for B using azomethine-H (28). Hand-ground, 2 mm-sieved, samples were assayed for acid ammonium oxalate extractable Fe and Al (19), dithionite-citrate-bicarbonate (DCB)-extractable Fe and Al (14), and percent clay by the pipette method (7). Fe and Al were determined by atomic absorption spectroscopy.

Leaching Experiment

Three-and-one-half kg of air-dried soil were mixed with enough P, K, Mg, and S to maintain adequate levels for plant growth (10) and packed in 16.5 cm x 18.5 cm diameter plastic greenhouse pots. The soils

were covered with a 2 cm layer of boron-free horticultural perlite to prevent puddling. A plastic nipple cemented into the bottom of each pot was fitted with a 5 cm length of 1 cm I.D. plastic tubing packed with polyester fiber providing a single outlet for leachate. Leachate was collected in a six liter plastic container with a snap-fit lid.

There were three boron treatments for each soil: 1) no boron (-B+L), 2) boron applied before leaching (+B+L), and 3) boron applied after leaching but before planting (+L+B). The rate of B application was 2.0 mg B/kg soil. Each treatment was replicated 3 times in a randomized block design.

The soils were gravimetrically brought to 80% of field capacity with distilled water. The +B+L treatment was prepared by dissolving 2.0 mg B/kg soil as sodium tetraborate in the second to last cm of water used to bring the soils up to 80% field capacity. After 14 days of equilibration, 0, 1, or 2 cm/day of distilled water was applied to each pot over a period of 10 weeks. Leachate was collected in increments of 5, 5, 7.5 and 7.5 cm for a total of 25 cm and each increment assayed for boron. The leachate from the +L+B pots was not fractionated nor assayed for B as this treatment duplicated treatment -B+L during the leaching phase of the experiment.

The leachate was analyzed using the azomethine-H method of Wolf (28) with a sample:buffer:azomethine-H ratio of 4:1:1. Where samples were turbid, 4 drops of 2 $\underline{M}$ $CaCl_2$ were added to a 40 ml subsample which, after 24 hours, was centrifuged at 24,000 g for 30 minutes. Where samples contained less than 0.20 mg B/liter approximately 1 liter

samples were passed through a 30 cm^3 column of Amberlite IRA-743[1] at

a flow rate of 5 ml/minute. The sorbed B was eluted with 50 ml of

2 $\underline{M}$ H$_2$SO$_4$ and brought to 100 ml, resulting in a ten-fold increase in

concentration. The columns were recharged with 50 ml of 1 $\underline{M}$ NaOH.

The eluent was analyzed for B using azomethine-H and a 2:2:1 ratio

of sample:buffer:azomethine-H (28).

Upon completion of the leaching, the perlite was removed, and five

2.5 cm dia. cores were taken from each pot and air-dried for 6 days.

The cores were taken to the full depth of soil. After mixing, a 100 g

sub-sample was retained and the remaining soil returned to the pot

followed by mixing. The subsamples were analyzed for hot-water-soluble

B as previously described.

Plant Growth Experiment

Following leaching the pots were returned to 80% of field capacity

and 2.0 mg B/kg soil applied to the treatment +L+B pots as previously

described. After six days equilibration, the pots were seeded with

inoculated New Zealand white clover (Trifolium repens L.) and covered

with 2 cm of fresh perlite. The plants were thinned to 15 per pot after

22 days. The pots were gravimetrically adjusted to 80% of field capac-

ity weekly, with supplemental watering as needed. Any leachate col-

lected was returned to the pots. Fluorescent tubes spaced 15.5 cm apart

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[1] A boron-specific ion exchange resin, manufactured by Rohm and Haas,

Philadelphia, PA 19105.

and 35 cm above the pots provided supplemental lighting with a 12 hour photoperiod. Temperature was maintained at 21°C days and 16°C nights.

The pots were harvested at 8, 13 and 18 weeks after planting and the plant material assayed for dry-matter yield and B content. B analysis consisted of dry-ashing 0.5 g dry plant samples in a 550°C muffle furnace for 4 hours, dissolving the ash in 5 ml of 3 $\underline{N}$ HCl, filtering, bringing to 50 ml with distilled water, and analyzing for B using azomethine-H with 2:2:1 ratio of sample:buffer:azomethine-H (28).

Following the final harvest, soil samples were removed from each pot, dried, and analyzed for hot-water-soluble B as described above.

Table 1. Analytical data for selected soils.

Soil Series	Location	Hot Water Soluble B	pH (2:1 H$_2$O:Soil)	Organic Matter	Clay	DCB Fe	DCB Al	NH$_4$-oxalate Fe	NH$_4$-oxalate Al
		µg/g		---------------------%---------------------					
Chehalis	1	0.62	6.2	2.1	21	1.4	0.11	0.73	0.26
	2	1.26	6.9	3.0	28	1.5	0.13	0.92	0.28
Jory	1	0.69	7.5	6.1	40	5.4	1.01	0.65	0.71
	2	0.84	5.4	6.6	43	5.2	1.07	0.61	0.75
	3	1.87	6.4	7.6	46	5.4	0.94	0.62	0.88
	4	0.55	7.2	4.5	31	5.0	0.71	0.78	0.45
Newberg	1	0.26	6.3	0.9	8	0.9	0.06	0.56	0.15
	2	0.85	6.8	1.1	10	0.9	0.08	0.61	0.17
	3	0.47	6.5	4.0	12	0.9	0.14	0.51	0.29
Willakenzie	1	1.15	6.3	3.6	29	1.3	0.20	0.48	0.23
	2	0.77	5.9	5.1	25	3.8	0.51	0.76	0.46
Woodburn	1	0.49	6.5	2.8	24	1.3	0.22	0.87	0.29
	2	0.42	5.8	2.7	23	1.2	0.23	0.86	0.29
	3	1.42	6.5	2.4	18	1.7	0.18	0.98	0.20
	4	1.06	6.1	4.7	23	1.5	0.21	0.73	0.23
	5	0.93	5.7	2.3	19	1.6	0.20	1.07	0.25

RESULTS AND DISCUSSION

Leaching experiment

The soil series chosen for this study represented a wide range in age, parent material, and landscape position. They are: two recent alluvial soils, Chehalis silty clay loam (Cumulic Ultic Haploxeroll, fine-silty, mixed, mesic) and Newberg sandy loam (Fluventic Haploxeroll, coarse-loamy, mixed mesic); a valley terrace soil, Woodburn silt loam (Aquultic Argixeroll, fine-silty, mixed, mesic); and two older soils of the valley foothills, Willakenzie silty clay loam (Ultic Haploxeralf, fine-silty, mixed, mesic) and Jory clay loam (Xeric Haplohumult, clayey, mixed, mesic). Analyses of the soils are presented in Table 1.

Recovery of applied boron in the leachate from the +B+L pots was calculated as

$$\% \text{ B Recovered} = \frac{\text{Leachate B (+B+L)} - \text{Leachate B (-B+L)}}{\text{B applied}} \times 100$$

where the contribution of the "native" soil B (leachate B from -B+L pots) is subtracted out and the recovery expressed as a percent of the 2.0 mg B/kg soil applied.

The recoveries of boron as a function of leachate collected are presented in Figure 1. Characteristically, the steepness of the curves decreased significantly as the leaching progressed. Several curves appear to approach a linear configuration towards the end of the leaching period, indicating a solid-solution equilibrium and a constant B concentration in the leachate.
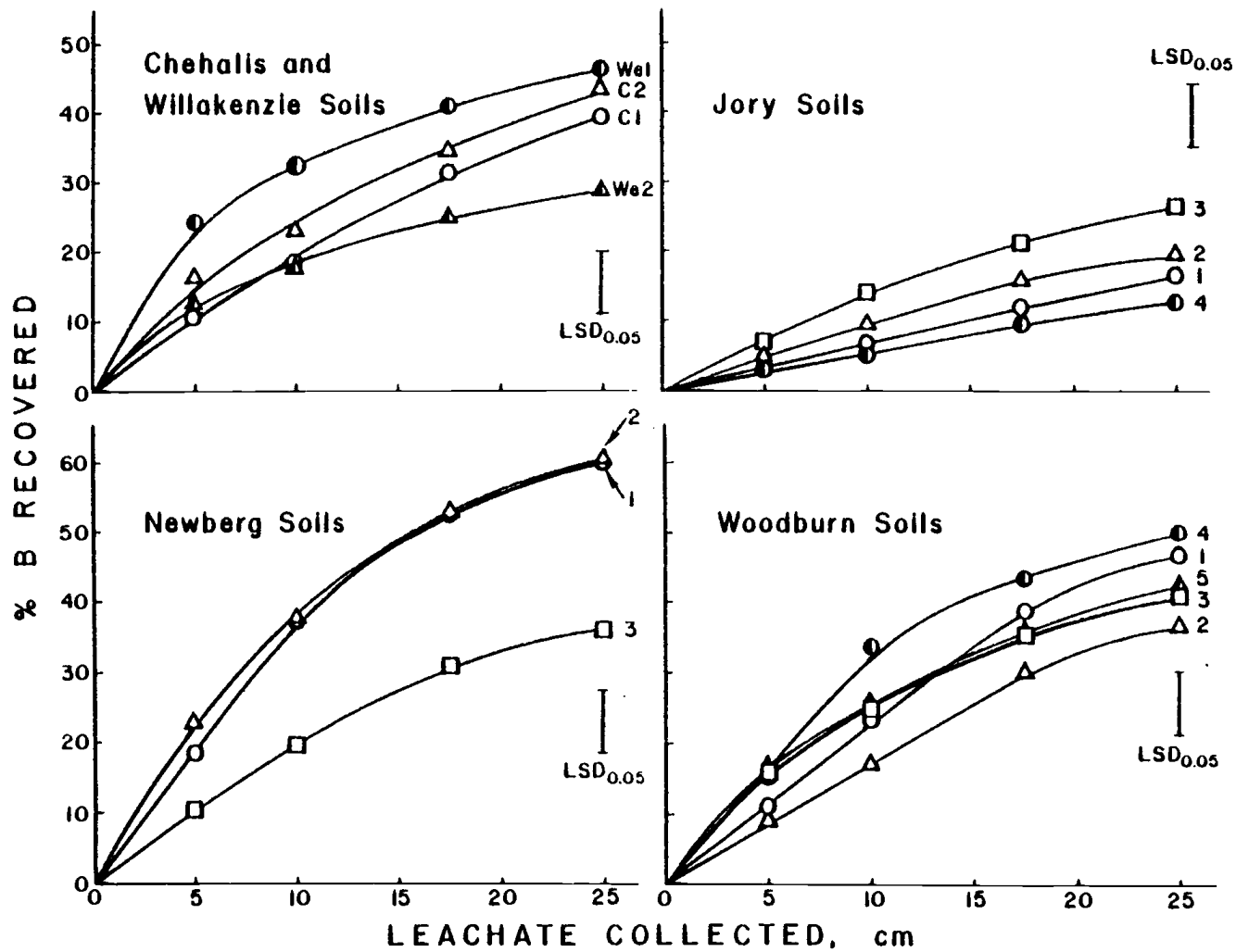
Figure 1.   Cumulative recovery of applied boron as a function of leachate collected. L.S.D. value applies to the final recoveries only.

The Chehalis soils and the Willakenzie 1 soil yielded comparable final recoveries of B (Fig. 1). The Willakenzie 2 soil, higher in organic matter and DCB-extractable Fe and Al content (Table 1), was significantly more boron-retentive (Fig. 1). The difference in B recovery could not be explained by a difference in clay content (Table 1).

The Jory soils yielded the lowest final recoveries of applied B (Fig. 1). These soils are comparatively high in organic matter, clay, and DCB-extractable Fe and Al (Table 1). Jory 1 and 4, with pH values above 7.0, retained the most B, but the final recoveries did not differ significantly ($p \leq 0.05$) from that of Jory 2. Thus, a reduction in B mobility due to high liming was not clearly demonstrated.

Of the sandy Newberg soils, 1 and 2 yielded high recoveries of B, with almost identical release curves (Fig. 1). Newberg 3 was considerably more B-retentive. The major difference between these soils is the much higher organic matter content of the uncultivated Newberg 3 while other properties were similar for these soils (Table 1). These results strongly indicate an important effect of organic matter in controlling the mobility of B.

The recoveries of B from the Woodburn soils were greater than from the Jory soils, ranging from 37 to 50% of the applied B (Fig. 1). The Woodburn soils were lower in organic matter, clay, and free Fe and Al oxides than the Jory soils (Table 1). No significant differences in B recovery due to soil properties were apparent among the Woodburn soils. In contrast to the Newberg soils, the higher organic matter content of Woodburn 4 did not result in greater B retention as compared to the other Woodburn soils. It may be that the nature, as well as the quantity, of soil organic matter may be important in the mobility of B.

The results suggest that organic matter, free Fe and Al oxides, and clay contents may be related to the mobility of B in soils. Regression of percent B recovered vs. soil properties yielded significant r^2 values for five soil properties (Table 2). The highest correlation was obtained with DCB-extractable Fe (r^2 = 0.76) although several other properties yielded comparable r^2 values (Table 2). The correlation could not be significantly increased by including any additional variables in a multiple regression model.

It was found that the soil properties clay, organic matter, DCB-extractable Fe, DCB-extractable Al, and ammonium oxalate-extractable Al were positively correlated with each other. Correlation coefficients ranged from 0.84 to 0.97. Ammonium oxalate-extractable Fe and soil pH were not correlated with other soil properties. The inter-correlation of the soil properties limits the interpretations that can be made from the results in Table 2. Without independence of these variables no definitive statement can be made regarding the soil constituent most responsible for B retention.

It is interesting to note the complete lack of correlation between percent B recovered and ammonium oxalate-extractable Fe (Table 2). This extraction is believed to remove only the recently precipated, hydrated forms of iron oxides (19) which are, in theory, the more surface active fraction and most important in adsorption reactions. The results obtained in this study do not support such a generalization.

The release of boron from the -B+L pots was also examined. Plots of B recovered vs. leachate collected yielded linear, or nearly linear, plots in all cases (not shown). The final, cumulative recovery of B was regressed against the initial hot-water-soluble B content of the soil

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Table 2. Coefficients of determination for the linear regression of % B recovered vs. various soil properties.

y Variable	x Variable	r^2
% B recovered	DCB-extractable Fe, %	0.76 **
	DCB-extractable Al, %	0.71 **
	Ammonium-oxalate-extractable Al, %	0.62 **
	organic matter, %	0.59 **
	clay, %	0.57 **
	pH	0.02 NS
	NH_4-oxalate-extractable Fe, %	0.00 NS

with a resulting r^2 value of 0.53 (significant at $p \leq 0.05$). A multiple regression approach yielded the relationship

$$B_r = 0.43 + 1.17\ B_s - 0.17\ O.M.$$
$$R^2 = 0.90**$$

where: B_r = B recovered, mg/pot

B_s = hot-water-soluble B, mg/pot

O.M. = organic matter, %

The negative regression coefficient for organic matter indicated that organic matter retards the movement of B rather than serving as a source of B. Substition of the clay, DCB-extractable Fe, DCB-extractable Al, or ammonium oxalate-extractable Al content for the organic matter content also yielded negative regression coefficients and R^2 values between 0.75 and 0.80. Again, interpretation is limited by the high correlations between these soil properties.

Sims and Bingham (25) identified dithionite-citrate-extractable iron as being most responsible for adsorption of B. Olson and Berger (21) found significant decreases in the B-adsorption capacity of soils when organic matter was removed with H_2O_2. Several workers have proposed that the mobility of boron is a function of soil texture, but failed to take into account such factors as organic matter content, iron and aluminum oxide content, and type of clay mineral (5, 17, 27). The results obtained in this study indicate that organic matter, iron and aluminum oxides, and/or clay are important in controlling the mobility of boron but further investigation is required to completely evaluate the role of each of these soil properties. Qualitative factors such as type of layer silicate clays, nature of Fe and Al oxide surfaces, and characteristics of the organic fraction also merit investigation.

Plant Growth Experiment

A vigorous stand of New Zealand white clover was obtained in all cases except for the Jory 4 soil. This soil contained herbicide residues, resulting in complete crop failure, and is excluded from all following results.

The dry matter yields for the three B treatments, averaged over 15 soils, are presented in Table 3. Analysis of variance indicated a significant ($p \leq 0.05$) treatment effect only for the first cutting. This effect was mostly associated with a reduction in yield for the +L+B treatment as compared to treatments -B+L and +B+L. Mild B-toxicity symptoms were noted on many of the young plants in the +L+B treatment, but these symptoms, as well as any adverse effect on yield, had disappeared by the second cutting. Clearly, there was no treatment effect on the total yield of three harvests. Yield differences between soils were statistically significantly ($p \leq 0.01$) whereas the soil x treatment interaction was not.

Plant B levels were significantly ($P \leq 0.01$) affected by B treatment for all three cuttings, with much of this effect being due to increases in plant B with treatment +L+B (Table 4). However, there were also significant effects due to soils and to soil x treatment interaction, although the F ratios were small in comparison to those for the B treatment effects (Table 5). The significant interaction was due to the tendency for the more B-retentive soils (e.g., Jory soils, Willakenzie 2) to show minimal differences in plant B across B treatments, whereas in the sandy Newberg soils there were large differences in plant B across treatments.

Table 3. Dry matter yields for three cuttings of white clover, means of 15 soils.

Cutting	Treatment			
	−B+L	+B+L	+L+B	
		g/pot		
1	5.86	6.03	5.68	*
2	6.39	6.52	6.64	NS
3	5.15	5.01	5.10	NS
Total	17.40	17.56	17.42	NS

Table 4. Boron content of dry white clover tissue, three cuttings, means of 15 soils.

Cutting	Treatment		
	−B+L	+B+L	+L+B
		B, µg/g	
1	83	86	118
2	75	81	92
3	80	88	99
Mean	79	85	103

Table 5. Variance ratio, F, for soil and treatment effects on the concentration of B in New Zealand white clover.

Source of variation	Degrees of freedom	Cutting		
		1	2	3
			F value	
Soils	14	7.4**	34.4**	33.7**
Treatments	2	342 **	126 **	120 **
Soils x Treatments	28	4.6**	10.4**	6.9**

The plant B levels were considerably higher than expected. Gupta
(11) considers plant concentrations of greater than 59 µg B/g to be in
the toxic range for red clover (Trifolium pratense L.). Dregne and
Powers (9) studied field-grown alfalfa (Medicago sativa L.) in the
Willamette valley and concluded that 20 µg B/g tissue was expected in
normal plants but that lower values, as well as deficiency symptoms,
were likely as soil test values for B dropped below 1.0 µg/g. The B
concentrations of 60 to 150 µg/g reported in this study are higher than
levels found in field-grown forage legumes.

Possible reasons for this inconsistency are that plant B levels may
have been higher due to high water use (as much as 2 cm per day) under
warm greenhouse conditions. Boron uptake is believed to be mainly
passive, following the transpirational flow of water (11, 20). Also,
reserves of B, not measured by the soil test, may have been plant avail-
able (1). It should be noted that other instances have occurred where
plant B levels in greenhouse-grown crops are much higher than for field-
grown crops (12, 26).

Plant B concentrations were not highly correlated with hot-water-
soluble B values obtained for the post-leaching soil samples from the
-B+L and +B+L treatments. The coefficients of determination were 0.00,
0.17, and 0.33 for the first, second, and third cutting, respectively.
The low r^2 values are consistent with the uniformly high plant B levels
observed for all soils and treatments. Soil test values were 0.47 to
2.34 µg B/g and included many values currently considered B-deficient
for crops such as white clover (10). Clearly, New Zealand white clover
was not sensitive to differences in hot-water-soluble soil B under

greenhouse conditions and other test crops may be preferred for future research.

Balance Sheet Approach

In an effort to evaluate the fate of applied B and the behavior of "native" soil B, a balance sheet was constructed for the -B+L and +B+L treatments (Fig. 2). For each soil-treatment combination, the distribution of B is plotted at three times: initially, after the leaching period, and after the cropping period. The leachate B (open bars) is carried over to the post-cropping plot to cumulatively account for all of the B.

For the -B+L treatments, the extractable B level increased in all soils except Woodburn 3 during the leaching period while measurable B was simultaneously recovered in the leachate (Fig. 2). The soil test levels tended to decrease during the cropping period, but there were fairly consistent increases in total B supply (soil extractable + leachate + plant B) (Fig. 2). These results are consistent with other work which has indicated a B supplying power not detected by a hot-water extraction (1, 2, 6). Mineralization of organic B as well as solid-solution equilibria may have been important in the capacity of the soils to release B.

The +B+L treatments afforded an estimation of the B "fixing capacity" of the soils studied. At the end of the leaching period, the following soils showed a significant net disappearance of B: all Jory soils, Willakenzie 2, and Newberg 3 (Fig. 2). Jory 4 (not shown) had a distribution very similar to that of Jory 1 at this time. These soils
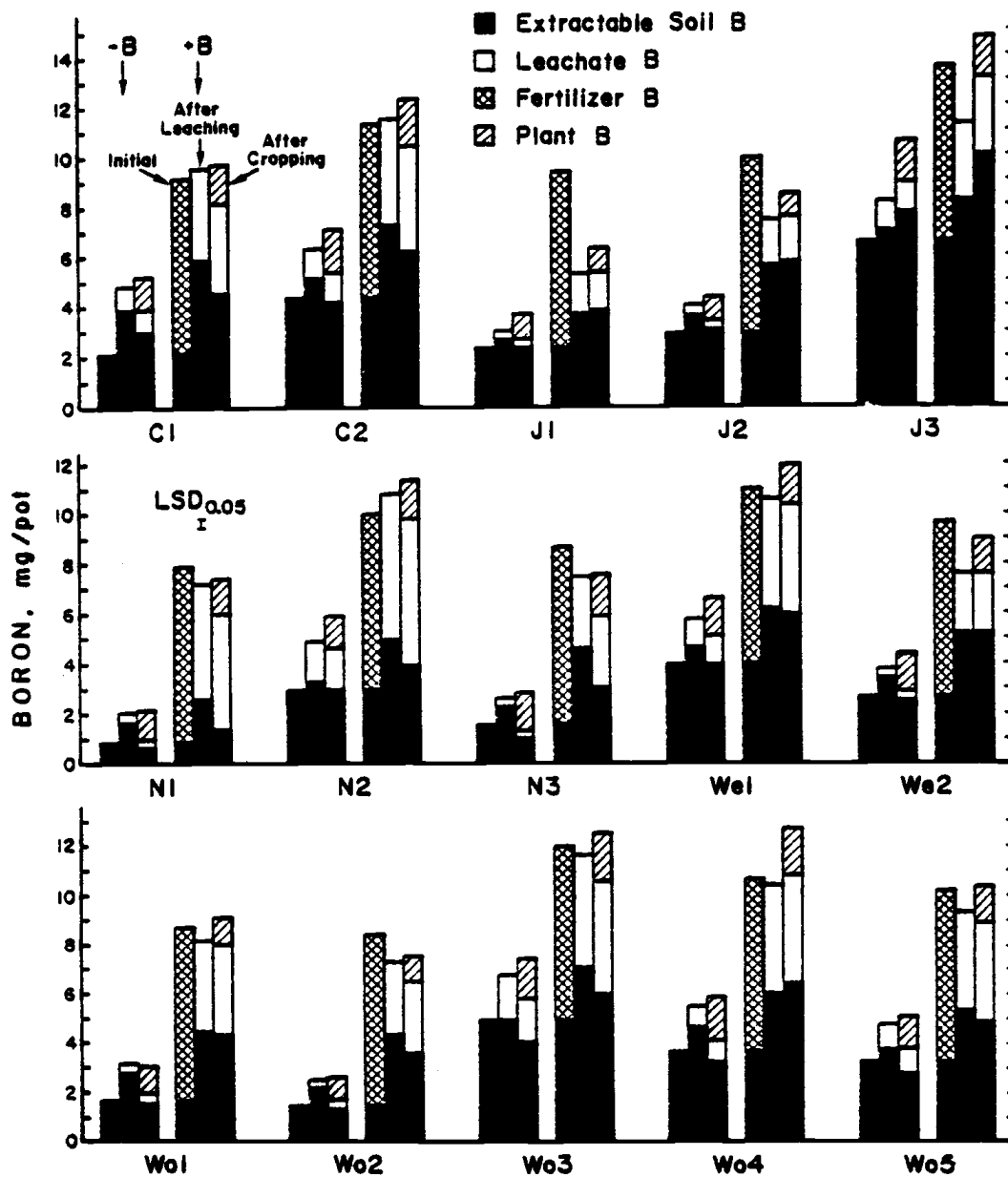
Figure 2. Distribution of boron at three times for 15 western Oregon soils, with and without applied boron. C = Chehalis, J = Jory, N = Newberg, We = Willakenzie, and Wo = Woodburn. L.S.D. value applies to the totals of B.

yielded the lowest percent recovery of applied B in the leachate
(Fig. 1), and tended to be high in organic matter, free iron oxides, or
both (Table 1). For all other soils the sum of the initial sources of B
approximately equaled the sum of the leachate B plus soil B at the end
of the leaching period (Fig. 2). There was a significant increase in
solubility or a mineralization of B in the Jory 3 and Woodburn 4 soils
during the cropping period resulting in a final recovery of B greater
than the sum of the original sources (Fig. 2).

An interesting contrast can be made between the Willakenzie 2 and
Newberg 3 soils (+B+L treatments). In Newberg 3 there was a decrease in
soil test B equivalent to the amount removed by the crop. In Willa-
kenzie 2, the soil test did not change, indicating an equilibrium con-
dition where the soil maintains a constant level of soluble B despite
crop removal of B. Chehalis, Newberg 1 and 2, and Woodburn 2 and 3
soils tended to parallel Newberg 3 in this regard while the Jory, Willa-
kenzie 1, and Woodburn 1, 4, and 5 soils were similar to Willakenzie 2
(Fig. 2). However, decreases in extractable soil B resulted from crop-
ping for the -B+L treatments in most cases (Fig. 2). Similarly, Baird
and Dawson (1) found that soils have differing capacities to maintain
levels of soluble B during cropping and that the five-minute, hot-water
extraction of B does not reflect this capacity. They proposed a more
intensive, six-hour soxhlet extraction to evaluate a soil's capacity to
replenish the soluble B removed by cropping. The results obtained in
this study suggest a B-supplying power that depends both on soil charac-
teristics and amount of boron in the soil system.

SUMMARY

In a greenhouse study of sixteen western Oregon soils, the downward
mobility of boron was influenced by soil properties. The amount of B
recovered in 25 cm of leachate from a 2.0 mg B/kg soil application
varied widely across soils, and was lower in soils high in organic
matter, iron and aluminum oxides, and clay. Statistical separation of
the importance of the soil properties in controlling the mobility of B
was complicated by intercorrelations among these variables. Further
study is needed to identify the relative importance of various soil
properties in controlling the mobility of B as well as the mechanisms
involved.

Greenhouse-grown New Zealand white clover (_Trifolium_ _repens_ L.)
was not sensitive to differences in extractable B despite its respon-
siveness to B under field conditions. Plant B levels were higher than
normally found in field-grown forage legumes, and were not highly corre-
lated with hot-water-soluble B levels.

A balance sheet approach indicated that the soils studied have a B
supplying capacity not reflected in the hot water extraction. Soils
without added B released significant amounts of B to leaching and
cropping, yet decreases in hot-water-extractable B were minimal. Soils
high in Fe and Al oxides and organic matter tended to "fix" a fraction
of the B applied at 2.0 mg/kg. This fraction was not recovered by
leaching, cropping, or hot-water-extraction. Of the soils receiving
applied B, some had well-buffered soil test B values during cropping
while others showed decreases in extractable B that paralled the B-
removal by the crop.

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SUMMARY AND CONCLUSIONS

In a preliminary study, a convenient, accurate method for determining the hot-water-soluble boron content of soils using azomethine-H was investigated and adopted. Extraction of soils with 0.02 $\underline{M}$ CaCl$_2$ resulted in clear, colorless solutions for colorimetric B determination and hot-water-soluble B values equal to those obtained with distilled water.

In a greenhouse study, 16 surface soil samples from five soil series were leached until 25 cm of water had been collected. Recovery of B in the leachate ranged from 13 to 61 percent of a 2.0 mg/kg application. The recovery of B decreased with increasing organic matter, iron and aluminum oxide and clay content of the soils but, as these properties were all positively correlated, it was difficult to evaluate the importance of individual constituents. No effect of soil pH over a range of 5.4 to 7.5 was observed.

After leaching, the soils were cropped with New Zealand white clover (Trifolium repens L.) and three cuttings were taken. Yield differences due to boron treatment were minimal and plant tissue concentrations of B were abnormally high, ranging from 60 to 150 µg/g.

A balance sheet was constructed and indicated a B-supplying power for all soils. Decreases in hot-water-soluble B levels were minimal after B was removed by leaching and cropping. Where B was applied to the soils, only those high in Fe and Al oxides and/or organic matter tended to retain a fraction of B not recoverable by leaching, cropping and hot water extraction. These results are consistent with some of the

literature which suggests that the hot-water extraction does not measure reserves of plant-available B.

Further study is required to clarify the behavior of boron in western Oregon soils. A more complete separation of the effects of soil properties on the mobility and plant-availability of B is needed. This could be better accomplished by selecting soils with a diversity in properties and without high correlations between the properties. There is also a surprising lack of good information concerning the mechanisms by which B is retained in soils including the importance of biological cycling of B.

The B fertility status of western Oregon soils also merits further investigation. Despite the widespread need for B fertilization in this area little soil test correlation or calibration research has been done. New Zealand white clover did not prove to be a satisfactory test crop, at least under greenhouse conditions, and other crops should be considered for further research. Highly boron-responsive crops such as beets, celery, cole crops, and alfalfa merit investigation. The results of this study suggest that surface horizons have a high B-supplying capacity. Other researchers have reported that it is the B status of the sub-soil, which plants draw upon during periods of drought, that determines whether or not B deficiencies will occur. Consideration of the sub-soil in future research is recommended.

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APPENDICES

Appendix Table 1. Hot-water-soluble boron by four methods for ten soils, Chapter 1.

Soil	Replication	ICP H$_2$O	ICP CaCl$_2$	Azomethine-H CaCl$_2$	Curcumin H$_2$O
		-------------------B, µg/g-------------------			
Bashaw	1	0.22	0.22	0.38	0.47
	2	0.16	0.16	0.42	0.46
	3	0.30	0.36	0.40	0.40
Chehalis	1	0.74	0.64	0.64	0.64
	2	0.60	0.58	0.64	0.65
	3	0.62	0.72	0.70	0.57
Dayton	1	0.14	0.14	0.20	0.27
	2	0.12	0.10	0.20	0.25
	3	0.20	0.22	0.16	0.31
Jory 1	1	0.90	0.84	0.88	0.98
	2	0.78	0.80	0.86	1.01
	3	0.74	1.06	1.04	1.04
Jory 2	1	0.16	0.22	0.24	0.31
	2	0.12	0.20	0.26	0.29
	3	0.16	0.24	0.25	0.33
Newberg	1	0.22	0.20	0.28	0.33
	2	0.24	0.18	0.26	0.29
	3	0.28	0.24	0.26	0.29
Willakenzie	1	1.26	1.38	1.34	1.42
	2	1.24	1.26	1.20	1.64
	3	1.26	1.18	1.16	1.75
Willamette	1	0.42	0.40	0.56	0.55
	2	0.48	0.38	0.62	0.56
	3	0.44	0.48	0.58	0.53
Woodburn 1	1	0.38	0.38	0.42	0.55
	2	0.42	0.32	0.42	0.54
	3	0.44	0.42	0.40	0.60
Woodburn 2	1	1.60	1.54	1.60	1.63
	2	1.60	1.58	1.52	1.65
	3	1.54	1.48	1.38	1.62

Appendix Table 2. Exact soil sampling site locations, Chapter 2.

Soil Series	Location	Site Location
Chehalis	1	In a cherry orchard 20 m south of a gravel road in the NE1/4, NW1/4, SE1/4 of Section 6, T12S, R4W, Linn Co.
	2	Three hundred meters northeast of a house in the SW1/4, SW1/4, SE1/4 of Section 12, T12S, R5W, Benton Co.
Jory	1	Just west of road, across from an intersection in the SW1/4, NE1/4 of Section 8, T8S, R1W, Marion Co.
	2	Just west of road, across from an intersection in the SW1/4, NE1/4 of Section 8, T8S, R1W, Marion Co.
	3	In a large field 200 m east of Davis Creek Road in the NW1/4, SW1/4 of Section 33, T6S, R1E, Marion Co.
	4	In a prune orchard 20 m south of Eola Hills Road in the SE1/4, SW1/4, NW/14 of Section 25, T5S, R4W, Yamhill Co.
Newberg	1	In the northeast corner of the OSU Botany/ Plant Pathology Farm in the NW1/4, SW1/4, SE1/4 of Section 36, T11S, R5W, Linn Co.
	2	Fifty meters northwest of a house in the SW1/4, SW1/4, SE1/4 of Section 12, T12S, R5W, Benton Co.
	3	Just east of a dirt road, on the edge of a wooded area in the NW1/4, SE1/4 of Section 13, T10S, R3W, Marion Co.
Willakenzie	1	Two hundred meters southeast of some grain bins on the H. Kuehne farm in the NE1/4, SW1/4 of Section 17, T3S, R3W, Yamhill Co.
	2	In a cherry orchard 40 m west of Bald Peak Road in the NE1/4, SW1/4 of Section 27, T2S, R3W, Yamhill Co.

Appendix Table 2. continued.

Soil Series	Location	Site Location
Woodburn	1	In a field on the Hyslop Farm in the SE1/4, SW1/4, SE1/4 of Section 5, T11S, R5W, Benton Co.
	2	In a field on the Hyslop Farm in the SE1/4, SW1/4, SE1/4 of Section 5, T11S, R5W, Benton Co.
	3	Fifty meters west of Carl Road, 60 m past Painter Loop Road in the NW1/4, NE1/4 of Section 4, T5S, R1W, Marion Co.
	4	Thirty meters south of Carl Road, 1/4 mile past Painter Loop Road in the SE1/4, NE1/4 of Section 4, T5S, R1W, Marion Co.
	5	Fifty meters west of Pulley Road, 3/8 mile before Whiskey Hill Road in the SE1/4, SW1/4 of Section 35, T4S, R1W, Marion Co.

Appendix Table 3a.　Soil chemical analysis, Chapter 2.

Soil Series	Location	pH	S.M.P.[1]	P	K	Ca	Mg	C.E.C.	Organic Matter	Base Saturation
				µg/g	µg/g	------meq/100 g-----			%	%
Chehalis	1	6.2	6.5	25	250	11.2	5.5	18.7	2.1	93
	2	6.9	6.7	53	422	17.7	6.0	26.1	3.0	95
Jory	1	7.5	6.9	14	137	19.3	0.8	20.3	6.0	∿100
	2	5.4	6.0	17	164	3.6	0.7	18.0	6.5	26
	3	6.4	6.0	20	86	8.8	2.0	22.7	7.6	49
	4	7.2	6.6	11	258	12.1	1.5	12.1	4.4	85
Newberg	1	6.3	6.9	13	250	7.8	3.3	13.1	0.9	89
	2	6.8	7.0	61	289	8.2	2.6	11.1	1.1	∿100
	3	6.5	6.6	16	241	11.7	3.9	19.6	4.0	83
Willakenzie	1	6.3	6.4	16	289	11.7	2.4	18.2	3.5	81
	2	5.9	6.0	32	469	7.8	1.6	19.5	5.2	54
Woodburn	1	6.5	6.6	97	211	10.4	1.2	15.3	2.8	79
	2	5.8	6.2	133	223	7.2	0.8	14.0	2.9	61
	3	6.5	6.7	32	164	9.6	1.2	13.4	2.4	84
	4	6.1	6.4	29	289	10.5	1.9	18.0	4.7	73
	5	5.7	6.3	48	125	7.3	1.2	13.0	2.5	66

[1] SMP lime requirement.

Appendix Table 3b. Fertilizer applications,[1] Chapter 2.

Soil		$Ca(H_2PO_4)_2 \cdot H_2O$[2]	K_2SO_4[3]	$MgSO_4$[4]	S[5]
		----------------g/pot----------------------			
Chehalis	1	0.93	0.39	----	0.08
	2	0.53	----	----	0.08
Jory	1	1.08	1.27	2.10	0.08
	2	1.04	1.06	2.10	0.08
	3	1.00	1.66	----	0.08
	4	1.13	0.33	----	0.08
Newberg	1	1.10	0.39	----	0.08
	2	0.42	0.09	----	0.08
	3	1.05	0.46	----	0.08
Willakenzie	1	1.05	0.09	----	0.08
	2	0.74	----	----	0.08
Woodburn	1	----	0.69	----	0.08
	2	----	0.60	2.10	0.08
	3	0.83	1.06	----	0.08
	4	0.87	0.09	----	0.08
	5	0.60	1.36	----	0.08

[1] All additions were made with reagent grade chemicals.

[2] Added such that:
Soil Test P, mg/kg + Applied P, mg/kg = 90 mg P/kg soil

[3] Added such that:
Soil Test K, mg/kg + Applied K, mg/kg = 300 mg K/kg soil

[4] Added to soils containing less than 1.0 meq Mg/100 g. Addition is equal to 1.0 meq Mg/100 g.

[5] Application to all pots as elemental sulfur. Equivalent to 23 mg S/kg (51 kg S/ha).

Appendix Table 4. Hot-water-soluble boron values, Chapter 2.

Soil	Location	Replication	Initial	After Leaching		After Cropping		
				-B+L	+B+L	-B+L	+B+L	+L+B
				--------------------B, μg/g--------------------				
Chehalis	1	1	0.58	1.12	1.84	0.86	1.48	1.46
		2	0.64	1.12	1.64	0.86	1.30	1.38
		3	0.64	1.08	1.56	0.92	1.24	1.44
	2	1	1.28	1.38	2.12	1.20	1.82	2.66
		2	1.26	1.40	2.02	1.42	1.70	2.64
		3	1.24	1.62	2.14	1.10	2.00	3.12
Jory	1	1	0.66	0.78	1.08	0.68	1.02	1.76
		2	0.68	0.84	1.16	0.74	1.20	1.62
		3	0.74	0.72	1.06	0.68	1.20	1.84
	2	1	0.78	1.00	1.66	0.96	1.76	1.92
		2	0.88	1.06	1.66	0.84	1.80	2.38
		3	0.86	1.06	1.52	0.92	1.58	2.56
	3	1	1.90	1.94	2.36	2.30	3.10	3.30
		2	1.84	2.08	2.32	2.24	3.00	2.90
		3	1.88	1.94	2.34	2.28	2.78	3.42
	4	1	0.58	0.74	1.24	----	----	----
		2	0.56	0.66	1.12	----	----	----
		3	0.50	0.76	1.16	----	----	----
Newberg	1	1	0.24	0.48	0.74	0.12	0.52	1.04
		2	0.28	0.48	0.78	0.20	0.32	0.88
		3	0.26	0.46	0.72	0.26	0.38	0.78

Appendix Table 4. continued.

Soil	Location	Replication	Initial	After Leaching		After Cropping		
				−B+L	+B+L	−B+L	+B+L	+L+B
					B, μg/g			
Newberg	2	1	0.78	0.90	1.36	0.92	1.08	1.72
		2	0.88	0.98	1.48	0.92	1.20	2.00
		3	0.88	0.94	1.38	0.80	1.20	2.20
	3	1	0.44	0.60	1.28	0.32	0.90	1.52
		2	0.50	0.72	1.30	0.30	0.94	1.12
		3	0.46	0.62	1.36	0.32	0.84	1.50
Willakenzie	1	1	1.10	1.32	1.86	1.08	1.72	2.32
		2	1.26	1.34	1.74	1.24	1.78	2.42
		3	1.08	1.32	1.74	1.20	1.74	2.12
	2	1	0.80	0.98	1.58	0.76	1.62	1.94
		2	0.76	1.02	1.46	0.74	1.42	2.22
		3	0.74	0.94	1.42	0.74	1.56	1.86
Woodburn	1	1	0.48	0.88	1.28	0.50	1.20	1.50
		2	0.50	0.72	1.36	0.48	1.20	1.86
		3	0.48	0.78	1.22	0.42	1.44	1.68
	2	1	0.42	0.64	1.14	0.40	0.98	1.56
		2	0.42	0.62	1.28	0.38	1.12	1.80
		3	0.42	0.62	1.32	0.40	1.08	1.34
	3	1	1.38	1.43	1.98	1.18	1.72	2.20
		2	1.46	1.43	2.06	1.16	1.66	2.26
		3	1.42	1.38	2.02	1.28	1.88	2.40

Appendix Table 4. continued.

Soil	Location	Replication	Initial	After Leaching		After Cropping		
				−B+L	+B+L	−B+L	+B+L	+L+B
				------------------B, μg/g------------------				
Woodburn	4	1	1.06	1.30	1.78	0.96	1.94	2.62
		2	1.06	1.30	1.72	0.92	1.92	2.20
		3	1.06	1.36	1.68	0.98	1.84	2.22
	5	1	0.94	1.04	1.62	0.78	1.36	1.88
		2	0.94	1.12	1.42	0.86	1.38	1.82
		3	0.92	1.10	1.54	0.82	1.58	2.18

Appendix Table 5a. Collected leachate volumes, Chapter 2.

Soil Series	Location	Replication	Increment[1] 1 -B+L	1 +B+L	2 -B+L	2 +B+L	3 -B+L	3 +B+L	4 -B+L	4 +B+L	1 +L+B
						Leachate volume, milliliters					
Chehalis	1	1	930	980	1000	880	1280	1390	1360	1470	4530
		2	900	1050	970	790	1450	1420	1490	1470	4570
		3	1060	1160	830	820	1340	1400	1400	1350	4670
	2	1	1070	1150	790	780	1400	1330	1410	1410	4520
		2	940	1050	920	790	1360	1360	1380	1510	4490
		3	1030	1020	840	850	1340	1390	1460	1440	4520
Jory	1	1	920	950	980	900	1350	1390	1410	1440	4520
		2	1020	980	860	860	1390	1370	1350	1430	4540
		3	960	880	980	1030	1270	1380	1440	1460	4500
	2	1	970	930	970	920	1270	1400	1400	1350	4520
		2	970	900	980	1080	1340	1350	1360	1390	4520
		3	940	960	880	1000	1340	1260	1390	1340	4580
	3	1	940	980	870	930	1360	1330	1370	1370	4600
		2	990	910	860	1010	1450	1300	1440	1400	4510
		3	1060	860	970	1030	1450	1390	1430	1420	3310[2]

[1] Increments 1 and 2 were 5.0 cm collected or 930 ml. Increments 3 and 4 were 7.5 cm collected or 1390 ml. Leachate from Treatment +L+B was collected in one 25.0 cm increment (4640 ml).

[2] Complete leaching of this pot was not possible.

Soil Series	Location	Replication	Increment								1
			1		2		3		4		
			−B+L	+B+L	−B+L	+B+L	−B+L	+B+L	−B+L	+B+L	+L+B
			----------------Leachate volume, milliliters----------------								
Jory	4	1	960	980	880	890	1350	1340	1410	1330	4560
		2	1090	1020	1020	820	1220	1390	1370	1410	4560
		3	1010	1060	820	860	1390	1360	1380	1390	4510
Newberg	1	1	910	890	900	940	1390	1380	1360	1350	4530
		2	970	1010	930	930	1590	1300	1380	1350	4550
		3	1020	930	910	940	1400	1350	1470	1360	4630
	2	1	1050	910	900	920	1290	1380	1340	1370	4560
		2	940	970	960	940	1330	1350	1390	1340	4570
		3	950	990	950	950	1370	1340	1400	1400	4560
	3	1	1040	1030	860	920	1350	1370	1370	1330	4510
		2	970	950	890	930	1360	1410	1400	1380	4570
		3	1030	990	910	860	1330	1370	1470	1360	4530
Willakenzie	1	1	1000	910	870	1010	1470	1290	1330	1340	4530
		2	940	950	980	990	1280	1370	1380	1380	4570
		3	1040	950	810	880	1350	1350	1390	1380	4530
	2	1	930	1020	1000	900	1350	1400	1340	1390	4320
		2	1020	1010	830	860	1370	1370	1410	1380	4540
		3	1030	1000	850	900	1430	1390	1360	1450	4560
Woodburn	1	1	960	980	960	910	1340	1390	1400	1360	4560
		2	970	940	890	1000	1360	1380	1410	1370	4580
		3	970	940	900	890	1350	1420	1360	1410	4580

Soil Series	Location	Replication	Increment								
			1		2		3		4		1
			−B+L	+B+L	−B+L	+B+L	−B+L	+B+L	−B+L	+B+L	+L+B
			----------------Leachate volume, milliliters----------------								
Woodburn	2	1	1000	990	810	920	1330	1370	1410	1420	4420
		2	990	940	870	920	1420	1360	1390	1350	4510
		3	940	940	900	900	1400	1420	1390	1380	4560
	3	1	900	980	900	1010	1460	1340	1400	1370	4610
		2	1070	1010	930	900	1280	1370	1400	1400	4510
		3	980	960	970	930	1400	1350	1370	1350	4560
	4	1	980	970	950	950	1310	1330	1370	1390	4570
		2	990	930	870	930	1440	1370	1360	1430	4540
		3	1040	1070	810	800	1330	1390	1360	1370	4620
	5	1	1000	990	880	860	1400	1440	1420	1390	4520
		2	1000	1010	870	870	1470	1380	1380	1370	4560
		3	990	1000	850	900	1390	1340	1430	1360	4480

Appendix Table 5b. Boron concentrations of collected leachate, Chapter 2.

Soil Series	Location	Replication	Increment							
			1		2		3		4	
			−B+L	+B+L	−B+L	+B+L	−B+L	+B+L	−B+L	+B+L
						B, μg/ml				
Chehalis	1	1	0.28	0.88	0.26	0.83	0.20	0.83	0.13	0.39
		2	0.28	0.93	0.24	0.86	0.22	0.89	0.12	0.54
		3	0.29	1.05	0.20	1.06	0.24	0.89	0.13	0.62
	2	1	0.34	0.97	0.33	0.95	0.30	0.96	0.22	0.71
		2	0.28	1.68	0.27	0.84	0.28	0.80	0.20	0.54
		3	0.28	1.45	0.27	0.88	0.25	0.83	0.17	0.63
Jory	1	1	0.049[1/]	0.15	0.049	0.20	0.041	0.22	0.085	0.27
		2	0.053	0.51	0.051	0.33	0.048	0.38	0.095	0.29
		3	0.055	0.29	0.056	0.36	0.068	0.40	0.080	0.35
	2	1	0.081	0.51	0.081	0.37	0.063	0.43	0.092	0.28
		2	0.082	0.17	0.070	0.25	0.065	0.33	0.104	0.28
		3	0.070	0.72	0.084	0.55	0.058	0.53	0.155	0.33
	3	1	0.33	0.70	0.32	0.68	0.24	0.52	0.22	0.43
		2	0.29	0.98	0.24	0.78	0.25	0.68	0.21	0.50
		3	0.26	0.91	0.29	0.80	0.23	0.69	0.20	0.50
	4	1	0.043	0.20	0.047	0.14	0.042	0.31	0.068	0.35
		2	0.057	0.18	0.052	0.18	0.039	0.27	0.100	0.22
		3	0.050	0.43	0.033	0.28	0.029	0.23	0.114	0.23

[1/] Concentrations for the −B+L leachates from soils Jory 1, 2, and 4, Newberg 1 and 3, Willakenzie 2, and Woodburn 1 and 2 are reported to three decimal places. These leachates were concentrated ten-fold prior to analysis.

Appendix Table 5b. continued.

Soil Series	Location	Replication	Increment							
			1		2		3		4	
			−B+L	+B+L	−B+L	+B+L	−B+L	+B+L	−B+L	+B+L
			B, µg/ml							
Newberg	1	1	0.067	1.44	0.042	1.41	0.033	0.84	0.098	0.48
		2	0.059	1.44	0.044	1.42	0.063	0.80	0.110	0.50
		3	0.048	1.41	0.061	1.58	0.037	0.93	0.126	0.48
	2	1	0.49	2.06	0.37	1.60	0.35	1.14	0.27	0.74
		2	0.38	2.22	0.39	1.46	0.36	1.08	0.23	0.51
		3	0.43	2.06	0.43	1.56	0.35	1.17	0.26	0.68
	3	1	0.026	0.76	0.025	0.61	0.032	0.60	0.149	0.41
		2	0.028	1.11	0.023	0.85	0.065	0.53	0.185	0.34
		3	0.029	0.44	0.038	0.80	0.017	0.72	0.105	0.45
Willakenzie	1	1	0.24	1.54	0.27	0.82	0.27	0.66	0.27	0.54
		2	0.24	2.40	0.23	0.82	0.23	0.57	0.22	0.57
		3	0.24	2.26	0.25	0.86	0.23	0.82	0.25	0.47
	2	1	0.056	0.77	0.064	0.45	0.053	0.42	0.091	0.31
		2	0.066	1.19	0.051	0.58	0.052	0.45	0.148	0.28
		3	0.062	0.89	0.051	0.42	0.034	0.37	0.097	0.28
Woodburn	1	1	0.079	1.02	0.078	0.98	0.064	0.92	0.095	0.43
		2	0.065	0.88	0.056	1.15	0.043	0.93	0.090	0.56
		3	0.082	0.80	0.073	0.71	0.055	0.76	0.073	0.54
	2	1	0.074	0.99	0.050	0.96	0.043	0.76	0.078	0.41
		2	0.070	0.44	0.045	0.55	0.030	0.67	0.109	0.46
		3	0.069	0.67	0.056	0.58	0.085	0.78	0.095	0.42

Appendix Table 5b. continued.

Soil Series	Location	Replication	Increment							
			1		2		3		4	
			−B+L	+B+L	−B+L	+B+L	−B+L	+B+L	−B+L	+B+L
			------------------------------B, μg/ml------------------------------							
Woodburn	3	1	0.51	1.69	0.46	1.15	0.39	0.86	0.24	0.49
		2	0.44	1.54	0.41	0.95	0.36	0.94	0.33	0.62
		3	0.42	1.56	0.35	1.05	0.32	0.92	0.32	0.64
	4	1	0.16	2.00	0.18	0.95	0.19	0.70	0.18	0.62
		2	0.23	1.72	0.23	0.81	0.18	0.66	0.21	0.43
		3	0.14	2.14	0.18	0.85	0.20	0.69	0.17	0.50
	5	1	0.31	1.49	0.31	0.92	0.24	0.65	0.14	0.41
		2	0.28	1.53	0.21	1.15	0.19	0.86	0.13	0.61
		3	0.30	1.38	0.24	0.85	0.19	0.64	0.18	0.50

Appendix Table 6a. New Zealand white clover dry matter yields, Chapter 2.

Soil Series	Location	Replication	Harvest 1 -B+L	Harvest 1 +B+L	Harvest 1 +L+B	Harvest 2 -B+L	Harvest 2 +B+L	Harvest 2 +L+B	Harvest 3 -B+L	Harvest 3 +B+L	Harvest 3 +L+B
			------------------------grams/pot------------------------								
Chehalis	1	1	6.53	6.41	5.01	6.80	8.10	6.78	5.08	4.44	4.76
		2	4.93	5.57	6.05	6.32	5.97	6.86	5.20	4.68	5.71
		3	6.03	5.76	5.40	4.63	5.91	5.54	4.11	4.65	4.55
	2	1	8.05	6.98	9.10	7.72	8.98	8.53	6.38	5.95	5.70
		2	9.28	8.58	8.87	7.80	8.05	7.90	6.35	6.70	6.01
		3	8.03	8.63	7.85	7.41	7.90	8.58	6.52	4.90	6.10
Jory	1	1	2.21	2.14	1.53	5.30	5.10	5.11	4.20	4.58	4.79
		2	2.31	2.51	2.69	5.25	5.49	6.49	5.64	5.24	5.68
		3	2.58	2.50	2.41	5.58	4.89	5.24	5.36	5.17	5.00
	2	1	2.55	2.46	2.27	4.74	5.24	4.85	5.08	4.65	3.55
		2	3.61	2.77	3.47	5.23	5.33	6.07	4.26	4.15	4.50
		3	2.85	3.15	2.92	4.79	3.85	4.54	4.61	3.70	4.35
	3	1	6.53	5.49	5.93	6.56	7.28	7.41	5.27	5.15	5.97
		2	7.84	5.52	5.55	7.59	7.71	6.86	7.08	6.22	5.81
		3	6.82	6.99	6.37	7.57	7.00	7.52	5.44	5.89	5.67
Newberg	1	1	6.38	7.02	6.31	7.35	6.44	7.12	5.19	5.85	5.66
		2	5.34	7.88	5.02	5.92	7.79	6.61	4.12	4.92	5.57
		3	6.34	7.47	5.75	6.02	3.59	6.58	3.81	3.67	5.10
	2	1	3.06	5.96	5.91	5.94	5.99	7.47	4.71	3.72	4.55
		2	6.62	6.62	6.76	7.51	7.33	7.22	4.60	4.52	4.70
		3	6.60	6.47	4.97	6.08	6.34	5.71	5.41	4.81	3.78

Appendix Table 6a. continued.

Soil Series	Location	Replication	Harvest								
			1			2			3		
			−B+L	+B+L	+L+B	−B+L	+B+L	+L+B	−B+L	+B+L	+L+B
			------------------------grams/pot------------------------								
Newberg	3	1	7.16	8.00	7.05	6.10	5.20	6.06	4.90	5.29	5.33
		2	8.48	7.89	7.89	7.68	7.43	7.67	5.28	5.75	5.52
		3	7.70	8.70	6.98	6.63	6.02	7.01	5.71	5.19	4.95
Willakenzie	1	1	6.97	7.57	7.80	6.52	7.49	6.01	5.02	4.34	4.98
		2	8.49	7.00	6.58	6.94	7.08	7.70	5.50	5.51	5.47
		3	6.95	7.71	7.22	6.43	7.60	7.95	6.11	6.04	5.53
	2	1	4.29	5.14	4.26	6.02	6.74	5.74	5.58	5.88	6.23
		2	5.59	5.47	4.25	6.95	7.03	6.75	6.62	6.84	5.64
		3	4.74	4.78	4.69	6.76	6.47	7.01	5.17	4.94	4.40
Woodburn	1	1	5.73	5.43	5.63	5.75	6.39	6.96	4.05	4.08	4.43
		2	6.03	4.89	6.21	6.26	5.96	6.40	4.92	4.65	5.12
		3	5.42	5.80	5.98	6.11	6.47	5.56	4.46	4.06	4.03
	2	1	3.44	4.03	3.58	4.39	5.43	5.15	4.06	3.89	3.79
		2	4.72	4.84	4.68	5.47	5.32	4.78	4.44	4.20	5.08
		3	4.00	4.05	4.68	4.50	5.38	5.00	4.02	4.15	3.96
	3	1	7.28	7.69	6.70	7.53	7.33	7.50	4.44	4.92	4.70
		2	7.87	8.19	6.13	6.66	8.13	7.83	5.53	4.35	5.05
		3	6.75	7.07	6.36	7.22	7.96	7.62	4.91	6.12	4.90
	4	1	7.80	6.74	8.12	8.52	7.96	7.55	6.79	4.54	5.94
		2	8.23	8.42	7.28	8.66	9.26	9.18	5.97	4.59	6.05
		3	7.80	8.96	7.80	7.78	8.10	6.78	4.59	5.64	5.86

Soil Series	Location	Replication	Harvest								
			1			2			3		
			−B+L	+B+L	+L+B	−B+L	+B+L	+L+B	−B+L	+B+L	+L+B
			----------------------grams/pot----------------------								
Woodburn	5	1	5.04	5.03	5.45	5.77	6.00	5.96	5.48	5.61	5.43
		2	4.67	6.05	4.95	5.89	5.82	6.81	4.86	4.92	4.96
		3	4.26	5.00	5.26	4.80	5.24	4.82	4.91	3.94	4.45

Appendix Table 6b.   Boron concentration in New Zealand white clover, Chapter 2.

Soil Series	Location	Replication	Harvest 1 -B+L	Harvest 1 +B+L	Harvest 1 +L+B	Harvest 2 -B+L	Harvest 2 +B+L	Harvest 2 +L+B	Harvest 3 -B+L	Harvest 3 +B+L	Harvest 3 +L+B
							B, µg/g				
Chehalis	1	1	83	91	123	81	87	91	74	97	101
		2	77	96	139	74	97	90	76	89	89
		3	84	90	127	84	83	100	76	77	92
	2	1	80	89	116	76	75	86	77	75	100
		2	74	83	121	80	75	92	81	78	93
		3	80	87	125	70	85	82	67	93	82
Jory	1	1	104	106	122	75	76	80	91	84	88
		2	89	87	95	63	60	71	76	87	83
		3	91	96	106	75	67	78	88	86	84
	2	1	94	95	121	60	63	76	70	80	84
		2	79	79	98	64	56	71	72	81	82
		3	87	89	109	60	70	77	70	79	83
	3	1	84	92	105	82	88	82	93	80	93
		2	81	81	95	72	80	79	88	86	88
		3	79	82	115	77	86	83	84	84	101
Newberg	1	1	81	80	138	76	77	116	61	72	105
		2	72	78	137	60	82	101	65	77	87
		3	79	76	169	70	94	127	60	86	99
	2	1	106	84	149	84	97	141	85	107	150
		2	71	76	121	72	88	138	90	97	130
		3	78	84	145	78	102	134	63	106	152

Appendix Table 6b. continued.

Soil Series	Location	Replication	Harvest 1 -B+L	+B+L	+L+B	Harvest 2 -B+L	+B+L	+L+B	Harvest 3 -B+L	+B+L	+L+B
						B, µg/g					
Newberg	3	1	90	86	115	84	88	112	79	93	104
		2	75	82	103	69	83	94	66	85	100
		3	82	81	114	77	93	102	75	95	106
Willakenzie	1	1	82	79	113	84	88	98	90	95	106
		2	68	81	92	70	80	88	83	86	98
		3	77	79	106	77	83	98	86	89	110
	2	1	102	96	128	80	80	72	90	87	82
		2	100	82	124	75	64	66	81	77	80
		3	106	97	121	78	69	70	83	79	76
Woodburn	1	1	79	76	98	76	66	82	74	72	89
		2	63	71	111	65	63	73	67	69	92
		3	75	79	112	66	69	84	70	73	93
	2	1	100	98	128	68	70	86	76	77	93
		2	70	81	124	60	64	91	78	73	88
		3	85	89	110	72	69	79	70	76	85
	3	1	88	92	119	80	96	95	102	115	118
		2	78	89	126	71	90	96	91	116	121
		3	79	88	123	77	95	111	96	122	131
	4	1	80	85	99	80	90	96	97	96	106
		2	74	79	108	77	92	98	102	107	118
		3	76	77	108	78	97	101	95	98	107

Appendix Table 6b. continued.

Soil Series	Location	Replication	Harvest								
			1			2			3		
			-B+L	+B+L	+L+B	-B+L	+B+L	+L+B	-B+L	+B+L	+L+B
			----------------------B, µg/g------------------------								
Woodburn	5	1	85	96	138	94	101	83	87	101	100
		2	88	91	110	82	100	76	87	97	95
		3	85	100	114	90	85	85	89	92	104

Appendix Table 7. Soil series profile descriptions,[1/] Chapter 2.

Chehalis Series

This soil occupies large areas on alluvial
bottom lands along the major streams and rivers.

Ap1--0 to 15 cm, dark-brown (10YR 3/3) light silty clay loam, dark brown (10YR 4/3)dry; moderate, very fine and fine, granular structure and weak, medium, subangular blocky structure; hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine interstitial pores; common worm casts; very drak grayish-brown (10YR 3/2) and very dark brown (10YR 2/2) coatings; neutral; clear, smooth boundary. 13 to 23 cm thick.

Ap2--15 to 28 cm, very dark brown (10YR 2/3; 10YR 2/2, uncrushed) silty clay loam, dark brown (10YR 4/3) dry; moderate, fine granular structure and weak, medium, subangular blocky structure; hard, friable, slightly sticky and slightly plastic; common very fine roots; many very fine interstitial and tubular pores; neutral; gradual, smooth boundary. 0 to 18 cm thick.

B21--28 to 51 cm, very dark brown (10YR 2/3; 10YR 2/2, uncrushed) silty clay loam, dark brown (10YR 4/3) dry; strong, fine granular structure; hard, friable, sticky and plastic; common very fine roots; many very fine and few fine tubular pores; neutral; gradual, smooth boundary. 15 to 25 cm thick.

B22--51 to 89 cm, very dark brown (10YR 2/3; 10YR 2/2, uncrushed) silty clay loam, brown (10YR 5/3) dry; moderate, very fine and fine, subangular blocky structure; hard, friable, sticky and plastic; common very fine roots; many very fine and fine tubular pores; neutral; clear, smooth boundary. 30 to 41 cm thick.

B3--89 to 114 cm, dark-brown (10YR 3/3) silty clay loam, brown (10YR 5/3) dry; moderate, fine and medium, subangular blocky structure; hard, friable, sticky and plastic; many very fine tubular pores; few very fine roots; neutral; clear, smooth boundary. 15 to 30 cm thick.

C--114 to 152 cm, dark yellowish-brown (10YR 4/4) silty clay loam, yellowish brown (10YR 5/4) dry; few, medium, faint, very dark grayish-brown (10YR 3/2) mottles; massive; hard, friable, sticky and plastic; many very fine pores; no roots; neutral.

Appendix Table 7. continued.

Jory Series

This gently sloping soil is on smooth ridgetops.

Ap--0 to 18 cm, dark reddish-brown (5YR 3/3) clay loam, reddish brown (5YR 4/3) when dry; moderate, fine, granular structure; friable, slightly hard, sticky, plastic; many fine roots; many very fine irregular pores; common fine and very fine concretions; medium acid (pH 5.8); abrupt, smooth boundary. 13 to cm thick.

A1--18 to 38 cm, dark reddish-brown (5YR 3/3) silty clay loam, reddish brown (5YR 4/4) when dry; strong, fine, granular structure; friable slightly hard, sticky, plastic; common fine roots; many very fine irregular pores; many fine concretions; medium acid (pH 5.8); clear, smooth boundary. 10 to 30 cm thick.

A3--38 to 53 cm, dark reddish-brown (5YR 3/3) heavy silty clay loam, reddish brown (5YR 4/4) when dry; strong, fine granular and subangular blocky structure; friable, slightly hard, sticky, plastic; common fine roots; many very fine irregular pores, common fine concretions; medium acid (pH 5.6); clear, smooth boundary. 8 to 18 cm thick.

B21t--53 to 71 cm, dark reddish-brown (5YR 3/4) clay, reddish brown (5YR 4/4) when dry; moderate, fine, subangular blocky structure; very firm, very hard, very sticky, very plastic; common fine roots; many very fine pores; few thin clay films on ped surfaces and in pores; few fine concretions; strongly acid (pH 5.4); clear, smooth boundary. 15 to 38 cm thick.

B22t--71 to 99 cm, dark reddish-brown (2.5YR 3/4) clay, reddish brown (2.5YR 4/4) when dry; moderate, medium, subangular blocky structure; very firm, very hard, very sticky, very plastic; few fine roots; common fine pores; many thin, black stains; many, thin and medium, patchy clay films on ped surfaces; few fine concretions; few fine fragments of basalt; strongly acid (pH 5.2); clear, smooth boundary. 25 to 51 cm thick.

B23t--99 to 142 cm, dark reddish-brown (2.5YR 3/4) clay, reddish brown (2.5YR 4/4) when dry; moderate, fine, subangular blocky structure; very firm, very hard, very sticky, very plastic; few fine roots; common very fine pores; thin and moderately thick continuous clay films on ped surfaces; many, fine and medium, black stains; few fine concretions; few fine fragments of basalt; very strongly acid (pH 5.0); gradual, smooth boundary. 30 to 91 cm thick.

Appendix Table 7. continued.

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Jory Series, continued:

    B3--142 to 173 cm, dark reddish-brown (2.5YR 3/4) clay, reddish
brown, (2.5YR 4/4) when dry; weak and moderate, fine, subangular blocky
structure; very firm, very hard, very sticky, very plastic; common fine
tubular pores; few thin clay films on ped surfaces and in pores; common,
fine, black stains; about 3 percent fine fragments of basalt; strongly
acid (pH 5.2).

Appendix Table 7.   continued.

Newberg Series

This soil is on recent alluvial flood plains.   Slopes are 0 to 3 percent.

Ap--0 to 20 cm, very dark grayish-brown (10YR 3/2) fine sandy loam, dark brown (10YR 4/3) dry; weak, fine, subangular blocky structure; soft, very friable, nonsticky and nonplastic; common very fine roots; common fine interstitial pores; medium acid; abrupt, smooth boundary. 18 to 30 cm thick.

AC--20 to 46 cm, dark-brown (10YR 3/3) fine sandy loam, dark brown (10YR 4/3) dry; weak, fine, subangular blocky structure; soft, very friable, nonsticky and nonplastic; few very fine roots; many very fine interstitial pores; slightly acid; clear, smooth boundary. 15 to 30 cm thick.

C1--46 to 76 cm, dark-brown (10YR 3/3 and 4/3) fine sandy loam, brown (10YR 5/3) dry; massive; soft, very friable, nonsticky and nonplastic; few very fine roots; many very fine interstitial pores; slightly acid; clear, wavy boundary. 20 to 36 cm thick.

IIC1--76 to 117 cm, mixed dark-brown (10YR 3/3 and 4/3), very dark grayish-brown (10YR 3/2), and dark grayish-brown (10YR 4/2) loamy fine sand, brown (10YR 5/3) dry; single grain; loose, nonsticky and nonplastic; many interstitial pores; few very fine roots; slightly acid; clear, wavy boundary. 38 to 56 cm thick.

IIIC2--117 to 152 cm, dark-brown (10YR 3/3 and 4/3) fine sandy loam, brown (10YR 5/3) dry; massive; soft, very friable, nonsticky and nonplastic; many interstitial pores; few very fine roots; slightly acid.

Appendix Table 7.   continued.

Willakenzie Series

This soil is on ridgetops and sides of low hills.   Slopes are dominantly
more than 5 percent.   Depth to sedimentary rock is 30 to 40 inches.

A1--0 to 10 cm, dark-brown (7.5YR 3/2) silty clay loam, brown
(7.5YR 5/3) when dry; weak, medium and fine, subangular blocky structure;
friable, hard, slightly sticky, slightly plastic; many very fine pores;
many fine roots; very few fine concretions; medium acid (pH 6.0); clear,
smooth boundary. 8 to 23 cm thick.

B1--10 to 30 cm, dark-brown (7.5YR 3/4) silty clay loam, strong
brown (7.5YR 5/6) when dry; moderate, medium and fine, subangular blocky
structure; friable, hard, sticky, plastic; many very fine pores; many
fine roots; medium acid (pH 6.0); clear, wavy boundary. 18 to 25 cm
thick.

B21t--30 to 46 cm, dark-brown (7.5YR 4/4) silty clay loam, strong
brown (7.5YR 5/6 when dry; moderate, fine and very fine, subangular
blocky structure; friable, hard, sticky, very plastic; common medium
and fine pores; many fine roots; few thin clay films in pores and on
some ped surfaces; medium acid (pH 5.0); clear, smooth boundary.
13 to 20 cm thick.

B22t--46 to 66 cm, dark-brown (7.5YR 4/4) silty clay loam, strong
brown (7.5YR 5/6) when dry; weak, medium, subangular blocky that breaks
to moderate, fine, subangular blocky structure; firm, hard, very sticky,
very plastic; many very fine pores; common fine roots; few very thin
clay films on ped surfaces; medium acid (pH 5.6); gradual wavy boundary.
15 to 30 cm thick.

B23t--66 to 81 cm, dark-brown (7.5YR 4/4) silty clay loam, strong
brown (7.5YR 5/6) when dry; weak, medium and fine that breaks to
moderate, very fine, subangular blocky structure; firm, hard, very
sticky, very plastic; many very fine pores; common fine roots; many
thin clay films; strongly acid (pH 5.4); abrupt wavy boundary. 13 to
18 cm thick.

IIC--81 to 91 cm, yellowish-red (5YR 4/6) loam; weak, fine,
angular blocky structure; friable, sticky, plastic; few fine pores;
few fine roots; common thick clay films on the coarse fragments;
80 percent strongly weathered siltstone fragments; very strongly acid
(pH 4.7); abrupt, smooth boundary. 8 to 10 cm thick.

IIR--91 cm, hard, fractured siltstone bedrock.

Appendix Table 7. continued.

Woodburn Series

This soil is on broad valley terraces.

AP--0 to 20 cm, very dark grayish-brown (10YR 3/2) silt loam, brown (10YR 5/3) dry; moderate, fine granular structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine interstitial pores; medium acid; abrupt, smooth boundary. 15 to 25 cm thick.

A3--20 to 41 cm, dark-brown (10YR 3/2) silt loam, brown (10YR 5/3) dry; moderate, fine, subangular blocky structure; slightly hard, friable, slightly sticky and slightly plastic; many very fine roots; many very fine pores; medium acid; clear, wavy boundary. 0 to 20 cm thick.

B1--41 to 61 cm, dark-brown (10YR 4/3) silt loam, brown (10YR 5/3) dry; moderate fine, subangular blocky structure; hard, friable, slightly sticky and plastic; common very fine roots; many very fine tubular pores; thin, clean, sand and silt grains on ped surfaces; medium acid; clear, smooth boundary. 0 to 23 cm thick.

B21t--61 to 81 cm, dark-brown (10YR 4/3) silty clay loam, pale brown (10YR 5/3) dry; common medium, distinct, dark-brown (7.5YR 4/4) and grayish-brown (10YR 5/2) mottles; weak, medium, prismatic structure and moderate, medium, subangular blocky structure; hard, firm, sticky and plastic; few very fine roots; many very fine and fine tubular pores; common, clean, fine sand and silt coatings on ped surfaces; common, thin, dark-brown (10YR 3/3) clay films on ped surfaces and in pores; slightly acid; clear, smooth boundary. 18 to 28 cm thick.

B3t--122 to 152 cm, dark-brown (10YR 4/3) silt loam, pale brown (10YR 5/3) dry; common, fine, distinct, dark-brown (7.5YR 4/4) and dark reddish-brown (5YR 3/2) mottles; weak, coarse, subangular blocky structure; hard, friable, sticky and plastic; many very fine and fine tubular pores; few moderately thick clay films in pores and few thin clay films on peds; slightly acid.