THE EFFECT OF LIME ON THE CHEMICAL COMPOSITION OF A CHARLOTTETOWN FINE SANDY LOAM AND THE EFFECT OF SEVERAL AMENDMENTS ON ITS CONTENT OF WATER-SOLUBLE BORON AS SHOWN BY SOIL AND PLANT ANALYSES

By

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ABSTRACT

Field, greenhouse and laboratory experiments were used to determine the results of liming a strongly acid soil and the effect of certain other amendments on its content of water-soluble boron.

The soil investigated, a Charlottetown fine sandy loam, is one of the best and most extensive agricultural soils on Prince Edward Island.

The field experiment, started in 1931, consisted of a three year rotation of potatoes, barley and clover. Limestone applications of 0, 500, 1,000, 1,500, 2,000 and 3,000 pounds per acre have been made periodically. Commercial fertilizer has been used for each potato crop and, since 1942, for each barley crop.

Chemical determinations made on soil samples taken in 1930, 1948 and 1951 included pH, exchangeable bases, base exchange capacity, total nitrogen and water-soluble boron.

Liming decreased soil acidity with the greatest amount of lime changing the pH value from approximately 5.0 to 6.0. Irrespective of the amount of limestone applied, decreases occurred in total nitrogen and exchangeable magnesium while exchangeable potassium increased.

From 1930 to 1948 water-soluble boron decreased approximately 30 per cent regardless of the amount of limestone applied. In 1948 a significant difference existed between the water-soluble boron content of limed and unlimed soils but not between soils receiving different rates of limestone.

The limestone treatments had little effect on soil acidity below plow depth.

Clover and barley yields were significantly increased by liming. This treatment did not affect potato yields but tended to increase the incidence of scab.

In a greenhouse experiment liming reduced boron availability as measured by plant and soil analysis. Two crops of ladino clover were grown and, although the calcium-boron ratios ranged from approximately 550 to 1 to 2,000 to 1, no visual symptoms of boron deficiency were observed.

There was a significant correlation between the water-soluble boron in the soil and the boron content of the clover.

The effect of calcium carbonate, magnesium carbonate, sodium hydroxide, gypsum, manure and alfalfa, on the water-soluble boron content of soil, was studied in a laboratory experiment.

Calcium and magnesium carbonates were equally effective in decreasing the water-soluble boron in soil. Gypsum was ineffective.

When the pH of the soil was raised from 4.70 to 7.32 with calcium carbonate the water-soluble boron decreased from 0.32 to 0.13 parts per million.

The water-soluble boron in soil was increased by applications of manure or alfalfa hay. The increases were proportional to the rates of application.

When expressed as parts per million of water-soluble boron, decreases occurring with calcium carbonate, whether applied alone or with manure or alfalfa hay, tended to be the same for any one rate of application irrespective of the amount of water-soluble boron present.

Applications of sodium hydroxide, to bring about a range of soil pH values from 4.82 to 9.72, were accompanied by decreases and then increases in water-soluble boron.

At comparable pH values of approximately 7.0 or less sodium hydroxide caused a smaller reduction in water-soluble boron than did either calcium or magnesium carbonate.

Calcium carbonate, applied to a soil previously treated with sodium hydroxide, caused less reduction in water-soluble boron than where applied in the absence of sodium hydroxide.

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INTRODUCTION

Lime in the form of marl, chalk or limestone occurs throughout the world and while the liming of agricultural land is far from a recent development the practice has greatly increased in the last fifty years. At the present time the use of lime as a soil amendment is generally considered as a major factor in crop production on much of the farm land in the more humid parts of this and other countries. However, it is also recognized that the availability of boron, an essential plant nutrient, may be adversely affected by the application of lime.

In recent years the use of lime as a soil amendment has increased considerably in various parts of the Maritime Provinces. This fact, together with reported instances of boron deficiency, makes it desirable to have information relative to liming and the effect of this practice on the availability of soil boron.

This investigation, based on field, greenhouse and laboratory studies, was carried out to learn what changes have occurred in soil properties and crop yields in a long term liming experiment being conducted at the Dominion Experimental Station, Charlottetown, Prince Edward Island and to determine how changes in pH value as well as applications of different sources of calcium and organic matter, both alone and in combination, affect the water-soluble boron content of soil.

II. LITERATURE REVIEW

The importance of lime in regard to soil acidity, plant growth, phosphate availability, soil structure, soil formation, fertilizer use and the reclamation of alkali soils has been discussed by Kelley (1940) who considers calcium of greater fundamental significance than nitrogen, phosphorus or potassium. Truog (1948) has indicated that the availability of all plant nutrients in the soil is affected to some extent by the amount of lime present, and Bradfield (1941) considers calcium carbonate part of a system which, directly or indirectly, influences most important reactions in soil chemistry. Fippin (1939) has made reference to the fact that lime is the key to the growth of most legumes and that this is possibly the greatest service of lime in agriculture.

According to McCall (1923) if a soil has an unfavorable hydrogen ion concentration, contains soluble iron, aluminum or manganese or has insufficient calcium for nutritive purposes an application of lime will be beneficial. In this connection Peech (1941) has included the direct nutrient effect of calcium and magnesium, the stimulation of microbial activity, improvement of the physical condition of the soil, the neutralization of hydrogen ions and the precipitation of toxic amounts of aluminum, manganese and iron among the beneficial effects to be derived from liming. Fippin (1939) and Truog (1947) have expressed similar views while Salter and Schollenberger (1939) have stated "liming increases the efficiency of utilization of the available water and fertility of the soil by correcting some factors unfavorable to plant growth, making possible more economical crop production and tending to conserve the soil."

Marshall (1948) has pointed out that the nature of the clay mineral in the soil may have considerable bearing on the response obtained from liming. This is explained by the fact that below 70 per cent saturation montmorillonite clays have a high energy of adsorption for the calcium ion while kaolinite releases calcium with equal ease irrespective of the degree of saturation. Cooper, Paden, Garman and Page (1948) have also suggested the importance of the type of clay mineral present in regard to the availability of ions for plant growth, while Reed and Cummings (1948) have stated that a higher degree of calcium saturation is required for comparable plant adsorption of calcium from soils with a 2:1 type colloid than from soils with a 1:1 type of colloid.

Aslander (1952) has attributed the unproductiveness of podzol soils to the absence of plant nutrients rather than to their acid reaction and believes a lasting fertility may be obtained by fertilization without liming. Truog (1918) has also suggested that acidity as such is not ordinarily the limiting factor in acid soils, while McCall (1923) considers the intensity of acidity to be of more importance than the quantity. Bryan (1923) believes that the greater the acidity of the substrate the less the power of plants to obtain calcium while Moser (1943) has presented evidence indicating that a liberal supply of available calcium is required for optimum growth in acid soils. Arron and Johnson (1942) have also shown that while acidity was not deleterious to plant growth a high calcium concentration in the nutrient solution was necessary for normal growth at low pH values.

While the influence of lime on potassium availability has been studied by various workers there is considerable variation in the results obtained. Harris (1937) has reported that in general increasing fixation occurred with increasing amounts of lime. Peech and Bradfield (1943) believe that in the absence of neutral salts the addition of lime results in the liberation of adsorbed potassium although if the soil contains neutral salts there may be an increase, a decrease or no change in the potassium concentration of the soil solution as the result will depend on the initial degree of base saturation of the soil. Pierre and Bower (1943) have expressed a somewhat similar view. Lucus and Scarseth (1947) have commented on the need for a proper balance between calcium and potassium in the soil while Jenny and Slade (1934) have suggested that microorganisms may be connected with decreased potassium availability following liming. York and Rogers (1947) have stated that as soils vary in their ability to fix applied potassium as well as in the nature and content of native potassium it is difficult to generalize in regard to the effect of lime on potassium availability.

Pierre and Browning (1935) as well as Lynd and Turk (1948) have pointed out that excess lime may be detrimental to crop growth while Albrecht and Schroeder (1941) and Albrecht (1946) have shown the importance of adsorbed hydrogen in the soil. These workers together with MacIntire and Hatcher (1942) and Naftel (1937a) have referred to the effect of lime on phosphorus availability. From the results reported it would appear that liming may increase, decrease or have little effect on phosphorus availability and as in the case of potassium it would be difficult to generalize in this regard.

In addition to the relation of lime to phosphorus and potassium the effect of lime on boron availability has been the object of a considerable amount of investigation since Warington (1923), Sommer and Lipman (1926) and McMurtrey (1929) showed boron to be an essential plant nutrient.

Although the amount of boron necessary for optimum growth is very small the work of Eaton (1944) shows that different plant species exhibit considerable variation in regard to their boron requirements and tolerances. Marsh (1942) as well as Piland, Ireland and Reisenauer (1944) have indicated that most legumes have a relatively high requirement and that dicotyledonous plants have a greater requirement than do monocotyledonous plants.

The function of boron in plants is somewhat obscure although Scripture and McHargue (1943) pointed out that it may be involved with protein metabolism while Cook and Millar (1949) suggest it regulates the intake of other ions. According to Berger (1949) it is also important in cell division and seems to be an essential component of the cell wall. Warington (1934) has indicated that calcium absorption is favored by the presence of boron while Brenchley and Warington (1927) have shown a relationship between the boron content of the substrate and the calcium metabolism of the plant. Marsh and Shive (1941) have also reported a relationship between the soluble calcium in plant tissue and the boron content of the substrate as well as between the calcium and boron in the plant. Jones and Scarseth (1944) have stated that plants grow normally only when a certain balance exists between the intake of calcium and boron while Purvis and Davidson (1948) consider a functional relationship to exist between the two with a high intake of either increasing the need for the other. Eaton (1944) has indicated that climatic factors may influence the movement of boron in plants.

Berger and Truog (1940) have pointed out that before visable symptoms of boron deficiency are manifest a reduction in yield usually occurs. It has been suggested by Dunklee and Midgley (1944) that with varying degrees of deficiency plants may show as many as ten different symptoms due to lack of boron. According to Berger (1949) terminal growth is invariably affected by boron deficiency and other symptoms include shortened internodes, blasted flowers and the failure of fruit and seed formation. Visual boron deficiency symptoms of more than seventy plants have been summarized by McMurtrey (1948) while Woodbridge (1950) has similarly summarized deficiency symptoms for various vegetables and tree fruits as reported by a number of Canadian investigators.

Although boron deficiency is often associated with alkaline and overlimed soils Beeson (1945) has pointed out that it is also found in regions of high rainfall where leaching may be excessive and the soils are strongly acid in reaction. Purvis (1939) considers that cropping practices together with a low original boron content may account for the unsatisfactory boron status of many podzol soils while Whetstone, Robinson and Byers (1942) believe soils of the Atlantic and Gulf coasts are apt to be deficient in boron. Eaton and Wilcox (1939) have indicated that the boron content of soils may be related to the nature of the soil forming materials and in this connection Whetstone, Robinson and Byers (1942) have reported that soils derived from igneous rocks and unconsolidated sediment have a low content while those derived from alluvium, limestone, shale and glacial drift are high in boron. According to Woodbridge (1950) boron deficiency symptoms have been observed in Canada from the Atlantic to the Pacific although the Maritime Provinces, Quebec, Ontario and British Columbia are the most seriously affected.

In regard to the factor or factors responsible for boron fixation in soils various opinions have been expressed in the literature. Eaton and Wilcox (1939) have suggested that heavy soils may fix boron more readily than light ones and that boron fixation is a relatively slow process and probably due to some kind of a chemical reaction. Midgley and Dunklee (1939) have also considered boron fixation to be of a chemical nature while Olson and Berger (1946) have expressed a similar view and consider it to be rapid, reversible and apparently associated with a group of minerals occurring in the clay fraction of soils. Parks and Shaw (1941) have suggested that fixation may be due to boron replacing aluminum in the aluminum-silicate crystal lattices and Parks (1944) concluded that fixation was due to this rather than to chemical precipitation, adsorption by clay or by organic matter. While Colwell and Cummings (1944) have reported a fundamental difference in the behavior of aqueous solutions of calcium, sodium and potassium metaborates Cook and Millar (1939) consider boron fixation cannot be entirely attributed to the formation of insoluble borates.

Naftel (1937b) has suggested that boron fixation may be of a biological nature while Hanna and Purvis (1941) as well as Tulin (1940) have indicated the possibility of boron fixation and depletion by increased microbial activity due to liming. Rogers (1947) found that sterilizing soil with toluene had no effect on boron fixation and interpreted this to mean that boron was not tied up in microbial tissue. Midgley and Dunklee (1939) have also discounted the importance of biological fixation and have suggested that organic matter activated by lime may fix boron. While Drake, Sieling and Scarseth (1941) have presented evidence showing that boron is not fixed by humus Parks and White (1952) have reported the retention of boron by humus systems. The latter investigators explained their results on the basis of chemical reactions between boron and di-hydroxy organic compounds.

According to Powers and Jordan (1950) liming, irrigation and applications of sulfur and manure may be used to remove excess available boron from soils.

III. REGION INVESTIGATED

A. Description of Prince Edward Island

Prince Edward Island, the smallest and most densely populated province in Canada, is part of the Canadian section of the physiographic region known as the Atlantic Coastal Plain of North America. The Island, with an area of approximately 2,184 square miles or 1,400,000 acres, is situated in the Gulf of St. Lawrence between 45°57' and 47°04' north latitude and between 61°55' and 64°25' west longitude (Figure 1). In general the surface relief is that of a flat to moderately undulating plain and much of the land, 85 per cent of which is cleared, is not more than 150 feet above sea level. Agriculture is the basic industry and slightly more than 50 per cent of the population live on farms.

The mean annual temperature is 42.2 F. and the mean annual precipitation is 43.07 inches. Extreme temperature fluctuations are uncommon and the precipitation is well distributed throughout the year. The average frost-free period as recorded from 1910 to 1945 at Charlottetown, the provincial capital, is around 155 days, this being somewhat longer than is general in Eastern Canada. Thus the climate, which may be termed humid-temperate, has favored the podsol type of soil development and the soils are leached, relatively low in plant nutrients and strongly acid in reaction.

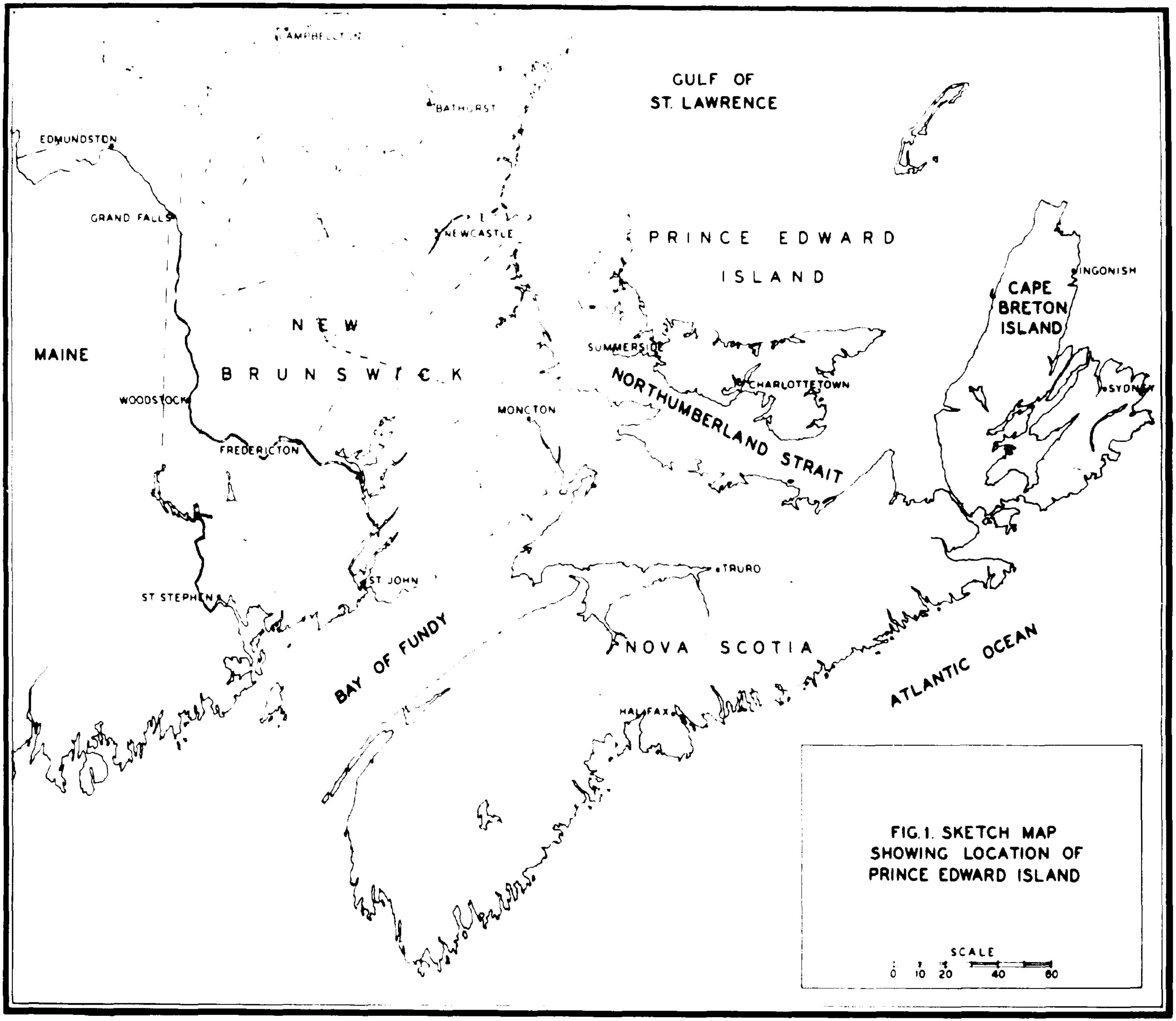


FIG. 1. SKETCH MAP SHOWING LOCATION OF PRINCE EDWARD ISLAND

B. Description of the Charlottetown Soil Series

The Charlottetown series, as described by Whiteside (1950), consists of medium to fine textured soils and has developed from glacial or glacio-residual material. It includes some of the most important agricultural soils of the Province and is found chiefly in the central part of the Island. This series covers approximately 486,000 acres or 35 per cent of the entire Province. A soil map of Prince Edward Island is shown in Figure 2 (in pocket).

The till from which the Charlottetown soils have developed has a close relationship to the local bed rock which is largely soft, micaceous red sandstone, shale or thinly bedded clay shale. In general the surface relief of the series is broadly undulating and drainage, both external and internal, is satisfactory. The soils of this series are practically free of surface stones or boulders and are easy to work but are erosive. The following profile description is that of a Charlottetown fine sandy loam as found under natural conditions and forest cover.

Horizon	Thickness	Description
A_0	½" to 2"	Slightly decomposed dark brown to black organic layer. Mainly mixed litter from spruce-maple association. pH 4.0.

Horizon	Thickness	Description
A_2	2" to 6"	Light ashy grey to white fine sandy loam. Structure when present tends to be platylike or laminated and readily crushes to a powdery condition. pH 4.2.
B_1	4" to 8"	Deep brownish-yellow to reddish yellow fine sandy loam. Weakly developed crumb structure. Loose, mellow and porous. pH 4.6.
B_2	6" to 12"	Weak reddish-brown or light brownish-red fine sandy loam. Weakly developed structure nutlike to small blocky in character, slightly firm, easily permeable. pH 4.6.
C	Below 20" to 24"	Reddish brown or brownish-red to red, fine sandy loam to sandy clay loam. Firm but permeable. Contains varying quantities of partially weathered sandstone fragments and the occasional sandstone boulder. pH 4.4.

Although the natural fertility of the Charlottetown series is not high these soils respond to good management and are capable of producing satisfactory yields. They are suited to a variety of common farm crops and approximately 60 per cent of the potato acreage of the Province is found on the Charlottetown series.

IV. EXPERIMENTAL PROCEDURE

A. Field Studies

In the spring of 1931 a field experiment with a three year rotation of potatoes, barley and clover was started at the Dominion Experimental Station, Charlottetown, Prince Edward Island. The experimental area, the soil of which is mapped as Charlottetown fine sandy loam, was divided into three ranges each of which contained three blocks of six plots. The ranges, which carried a different crop in the rotation each year, were separated by 20 foot alleyways. The plots, separated by four foot pathways, were 13.2 feet by 55 feet with an area of one-sixtieth of an acre. A field plan of the experiment is given in Figure 3.

Soil treatments. Ground limestone treatments were randomized within each block. The rates used were:

(1) Check

(2) 500 pounds per acre

(3) 1,000 pounds per acre

(4) 1,500 pounds per acre

(5) 2,000 pounds per acre

(6) 3,000 pounds per acre

Prior to 1942 limestone was applied every six years. Beginning in 1942 it was applied every three years and that year both the barley and clover crop received limestone. With

Plots	Range 3		Range 2		Range 1	
1	2000	Block 7	0	Block 4	2000	Block 1
2	0		1500		3000	
3	1500		3000		1500	
4	3000		2000		0	
5	1000		500		500	
6	500		1000		1000	
7	1000	Block 8	1500	Block 5	1500	Block 2
8	3000		0		2000	
9	2000		3000		0	
10	0		2000		500	
11	1500		1000		3000	
12	500		500		1000	
13	3000	Block 9	0	Block 6	1500	Block 3
14	1500		1500		0	
15	500		3000		2000	
16	1000		2000		500	
17	2000		500		3000	
18	0		1000		1000	

Fig. 3. Plan of field experiment with limestone treatments in lb./A.

this exception limestone was only applied for the barley crop. The crop and year of limestone application is shown in Table I.

From 1931 to 1941 inclusive a 4-8-6 fertilizer at 1200 pounds per acre was used for the potato crop. Beginning in 1942 this was changed to a 4-8-10 analysis and in addition 300 pounds per acre of a 2-12-10 analysis was applied to the barley crop.

Crop yields. The yields of all crops were recorded each year. In the case of potatoes the crop was examined for scab as in 1930 the experimental area produced scab free potatoes. Yields of this crop were expressed in bushels per acre of marketable tubers. Barley yields were recorded in bushels per acre of threshed grain and clover yields in tons per acre of air dry hay.

Soil samples. After the experiment was laid out and before any treatments were applied surface and subsoil samples were taken from plots 3 and 9 in range 1, plots 5 and 13 in range 2 and plots 3, 9 and 16 in range 3. In 1948 surface soil samples were obtained from each plot in the experiment. In 1951 subsoil samples, corresponding to those taken at the beginning of the experiment, were taken. All the samples were of a composite nature with the surface samples representative of the 0-6 inch depth and the subsoil samples representative of the 6-12 inch depth.

When the 1948 samples were taken range 1 had received four applications of limestone while ranges 2 and 3 had been limed

TABLE I

CROP AND YEAR OF LIME APPLICATION

Year	Ranges 3	2	1
1931	Clover	Potatoes	Barley (lime)
1932	Potatoes	Barley (lime)	Clover
1933	Barley (lime)	Clover	Potatoes
1934	Clover	Potatoes	Barley
1935	Potatoes	Barley	Clover
1936	Barley	Clover	Potatoes
1937	Clover	Potatoes	Barley (lime)
1938	Potatoes	Barley (lime)	Clover
1939	Barley (lime)	Clover	Potatoes
1940	Clover	Potatoes	Barley
1941	Potatoes	Barley	Clover
1942	Barley (lime)	Clover (lime)	Potatoes
1943	Clover	Potatoes	Barley (lime)
1944	Potatoes	Barley (lime)	Clover
1945	Barley (lime)	Clover	Potatoes
1946	Clover	Potatoes	Barley (lime)
1947	Potatoes	Barley (lime)	Clover
1948	Barley (lime)	Clover	Potatoes
1949	Clover	Potatoes	Barley (lime)
1950	Potatoes	Barley (lime)	Clover
1951	Barley (lime)	Clover	Potatoes

five times. In 1951, when subsoil samples were obtained, each of the ranges had received an additional limestone treatment.

B. Greenhouse Studies

In the fall of 1950 a greenhouse experiment was initiated at Ottawa, Canada. The surface six inches of a Charlottetown fine sandy loam soil, obtained from the Dominion Experimental Station at Charlottetown, Prince Edward Island, was screened, mixed and placed in gallon pots. This soil was considered to be comparable to that in the check plots of the previously described field experiment.

The potted soil was not maintained at a definite moisture content but adequate moisture was provided at all times by surface applications of tap water. There was not, however, enough water applied at any one time to cause leaching through the peat moss plug in the hole at the bottom of the pot.

Soil treatments. The experiment consisted of four treatments each of which was replicated three times. The treatments were:

(1) Check

(2) An 0-10-10 fertilizer at 800 pounds per acre

(3) Calcitic limestone at 2 tons per acre

(4) Treatment (2) + Treatment (3)

The limestone was mixed with the air dry soil before potting while the fertilizer was applied to the potted soil as a blanket application at a depth of two inches.

<u>Seeding and harvesting</u>. In December seven ladino clover seeds were planted in each pot and later thinned to two plants per pot. The clover, which was seeded at the one-half inch depth, was cut at the early bloom stage with the last of five cuts being made on October 2, 1951. The material cut from each culture was allowed to air dry before recording the weight. When harvesting was complete the five harvests of the replicates were combined to make a composite sample for each treatment.

<u>Soil sampling</u>. Following the fifth cut of clover soil samples were taken with a tube which reached to the bottom of the pot. Three samples were taken from each pot and replicates combined to give composite samples representing each of the four treatments.

<u>The second clover crop</u>. The cultures were not watered after the final cut of the 1950-51 crop and further growth was prevented by reworking the surface soil. In December 1951 the soil was removed from the pots and reworked. Other than applying limestone at 1½ rather than 2 tons per acre the soil treatments as well as the seeding and harvesting procedures were similar to those given for the 1950-51 crop. In the case of the 1951-52 crop the clover was cut four times and composite soil samples were taken from the pots in May 1952.

C. Laboratory Studies

In August 1951 a laboratory experiment was set up at the Division of Chemistry, Science Service, Ottawa, Canada. The soil used was representative of the 0-6 inch depth in the check plots in ranges 1 and 3 of the previously described field experiment at Charlottetown, Prince Edward Island. The plots were sampled in May 1951.

Soil treatments. The experiment involved nine series. The treatments within each series were:

Series 1 $CaCO_3$ at 0, 1, 2, 4, 6 and 8 tons per acre.

Series 2 $CaSO_4.2H_2O$ at 0, 1.72, 3.43, 6.86, 10.30 and 13.73 tons per acre. These rates added the same amount of calcium as was supplied by the $CaCO_3$ in series 1.

Series 3 $MgCO_3$ at 0, 0.84, 1.68, 3.36, 5.04 and 6.74 tons per acre. These rates provided a neutralizing power equivalent to that of the $CaCO_3$ in series 1.

Series 4 Manure at 0, 10, 20, 40, 60 and 100 tons per acre.

Series 5 $CaCO_3$ and manure together at the rates used in series 1 and 4.

Series 6 Alfalfa hay at 0, 10, 20, 40, 60 and 100 tons per acre.

Series 7 $CaCO_3$ and alfalfa hay together at the rates used in series 1 and 6.

Series 8 1.N NaOH at such rates as to give a range of pH values from approximately 5.0 to 9.5.

Series 9 Sufficient 1.N NaOH to raise the pH value of the soil to approximately 8.5 and then $CaCO_3$ treatments as in series 1.

The calcium carbonate, gypsum, magnesium carbonate and sodium hydroxide used were boron free. On an air dry basis the manure used contained 17.8 parts per million of total boron and the alfalfa hay 50.8 parts per million.

Experimental procedure. The soil was air dried, passed through a 2 mm. sieve, thoroughly mixed and weighed out in 200 gram samples. To facilitate mixing with the soil the manure and alfalfa hay were air dried and ground in a Wiley mill. These materials were added to the soil on the basis of their original moisture content.

The various materials were thoroughly mixed with the soil which was placed in half pint waxed containers. Water, equal to 50 per cent of the moisture holding capacity of the soil was added and the treated samples allowed to stand until approximately air dry. At that time the samples were thoroughly mixed and remoistened. They were maintained in that condition for two months. At that time they were allowed to air dry and were prepared for chemical analysis.

V. METHODS OF ANALYSIS

A. Soils

All analyses except those for nitrogen were made on samples of air dry soil ground to a fineness of 2 mm. Nitrogen determinations were made on samples ground to 0.5 mm. fineness.

A soil water ratio of 1 to 2.5 was used for pH determinations which were made with a glass electrode.

Total nitrogen was determined by the Kjeldahl method as given by the Association of Official Agricultural Chemists (1945).

Exchangeable bases and base exchange capacity were determined by the methods of Peech, Alexander, Dean and Reed (1947). In the determination of base exchange capacity the adsorbed ammonia was distilled after extraction with sodium chloride. Micromethods were used in the determination of the exchangeable cations.

Water-soluble boron was determined colorimetrically using tumeric as proposed by Naftel (1939). In this determination 10 grams of soil and 50 ml. of water were boiled under refluxing conditions for five minutes. After cooling to room temperature the water extract was separated from the soil by centrifuging. A photoelectric colorimeter was used to determine the intensity of color developed with the tumeric reagent.

B. Plants

The air dry plant material was ground in a Wiley mill prior to analysis.

Calcium was determined by dry ashing as given by the Association of Official Agricultural Chemists (1950).

Total boron was determined colorimetrically using tumeric as proposed by Naftel (1939). The plant material was dry-ashed in the presence of $Ca(OH)_2$ and the final color comparisons were made with a photoelectric colorimeter.

VI. RESULTS AND DISCUSSION

A. Field Studies

1. Analysis of Soils

The results of analysis of seven surface soil samples taken in 1930 are presented in Table II. The strongly acidic nature of the soil is shown by the pH values and the per cent base saturation. While there is considerable variation in respect to exchangeable magnesium, and to a lesser extent in the case of exchangeable potassium, the values for nitrogen indicate no great differences in the organic matter content of the experimental area.

The analytical data for the 54 surface soil samples collected in 1948 are given in Table III. It will be noted that with the exception of those plots which did not receive limestone, the values for exchangeable magnesium are consistently much higher in range 3 than in either range 1 or range 2. It is possible that in one of the years range 3 was limed with dolomitic rather than calcitic limestone. The limestone, dolomitic or calcitic, used on Prince Edward Island is imported from Nova Scotia or New Brunswick. The data show that the water-soluble boron content of the soil from plots 1, 2 and 3 in range 1 is approximately double that found in any of the other soils. As these three plots occur together at one

TABLE II

CHEMICAL ANALYSIS OF SOIL SAMPLES COLLECTED IN 1930

Range	Plot	pH	Exchangeable Cations* Ca	Mg	K	Exchange Capacity*	Base Saturation	Nitrogen
			me	me	me	me	%	%
1	9	5.4	3.54	0.30	0.20	8.29	48.7	0.21
2	13	4.9	3.07	0.60	0.18	8.75	44.0	0.24
2	5	5.2	2.97	0.25	0.22	9.82	35.0	0.21
3	16	4.7	2.29	0.55	0.19	10.54	29.4	0.24
1	3	5.3	3.36	0.40	0.17	8.45	46.5	0.21
3	3	5.2	1.43	0.15	0.11	9.82	17.2	0.22
3	9	5.2	1.35	0.15	0.06	9.80	15.9	0.20

* In 100 gm. soil.

TABLE III

CHEMICAL ANALYSIS OF SOIL SAMPLES COLLECTED IN 1948

Range	Plot	pH	Rate of Limestone Application	Exchangeable Cations* Ca	Mg	K	Exchange Capacity*	Base Saturation	Nitrogen	Boron
			lb./acre	me	me	me	me	%	%	ppm
1	4	4.8	0	2.39	0.12	0.29	9.88	28.3	0.19	0.35
1	9	4.8	"	2.30	0.14	0.26	9.60	28.2	0.18	0.34
1	14	4.7	"	1.79	0.09	0.23	9.02	23.4	0.17	0.30
2	1	4.9	"	2.22	0.14	0.26	9.53	27.5	0.20	0.33
2	8	5.1	"	2.94	0.11	0.24	9.31	35.4	0.18	0.34
2	13	5.1	"	2.28	0.10	0.32	9.55	28.3	0.18	0.30
3	2	5.0	"	2.32	0.18	0.24	9.60	28.5	0.19	0.33
3	10	5.1	"	2.85	0.15	0.28	9.86	33.3	0.19	0.35
3	18	4.9	"	1.89	0.13	0.33	9.45	24.9	0.19	0.31

* In 100 gm. soil.

TABLE III(continued)

Range	Plot	pH	Rate of Limestone Application	Exchangeable Cations* Ca	Mg	K	Exchange Capacity*	Base Saturation	Nitrogen	Boron
			lb./acre	me	me	me	me	%	%	ppm
1	5	4.9	500	3.11	0.13	0.30	9.58	37.0	0.19	0.30
1	10	4.9	"	3.11	0.14	0.25	9.68	36.2	0.20	0.32
1	16	5.0	"	2.52	0.12	0.23	8.15	35.2	0.19	0.27
2	5	5.3	"	3.37	0.07	0.23	9.06	40.5	0.19	0.28
2	12	5.2	"	3.34	0.07	0.26	9.45	38.8	0.19	0.29
2	17	5.1	"	3.03	0.09	0.33	9.37	36.8	0.19	0.26
3	6	5.4	"	3.38	o.32	0.24	9.88	39.9	0.21	0.33
3	12	5.4	"	3.33	o.24	0.25	9.94	38.4	0.19	0.29
3	15	5.1	"	2.07	0.16	0.23	9.25	26.6	0.18	0.28

* In 100 gm. soil.

TABLE III(continued)

Range	Plot	pH	Rate of Limestone Application	Exchangeable Cations* Ca	Mg	K	Exchange Capacity*	Base Saturation	Nitrogen	Boron
			lb./acre	me	me	me	me	%	%	ppm
1	6	5.1	1000	3.99	0.14	0.29	9.76	35.1	0.20	0.32
1	12	5.1	"	4.19	0.16	0.20	9.47	48.1	0.18	0.30
1	18	5.0	"	2.73	0.12	0.22	9.19	33.4	0.17	0.28
2	6	5.5	"	4.23	0.11	0.29	9.19	50.4	0.20	0.32
2	11	5.4	"	4.23	0.09	0.23	9.68	47.0	0.18	0.29
2	18	5.1	"	2.76	0.08	0.30	9.19	34.2	0.19	0.28
3	5	5.5	"	3.60	0.41	0.24	10.05	42.3	0.19	0.32
3	7	5.6	"	3.92	0.40	0.21	10.00	45.3	0.19	0.32
3	16	5.3	"	2.93	0.33	0.32	9.25	38.7	0.18	0.26

* In 100 gm. soil.

TABLE III (continued)

Range	Plot	pH	Rate of Limestone Application	Exchangeable Cations* Ca	Mg	K	Exchange Capacity*	Base Saturation	Nitrogen	Boron
			lb./acre	me	me	me	me	%	%	ppm
1	3	5.4	1500	4.89	0.13	0.29	10.17	52.4	0.19	0.53
1	7	5.4	"	4.77	0.11	0.25	9.60	53.5	0.19	0.30
1	13	5.1	"	3.69	0.12	0.22	8.94	45.2	0.18	0.27
2	2	5.6	"	4.65	0.12	0.16	10.23	48.1	0.20	0.31
2	7	5.5	"	4.97	0.09	0.25	9.60	55.4	0.19	0.32
2	14	5.5	"	4.52	0.13	0.27	9.51	51.8	0.18	0.27
3	3	5.6	"	4.24	0.46	0.30	9.86	50.7	0.19	0.30
3	11	5.5	"	3.29	0.28	0.23	9.60	39.6	0.18	0.28
3	14	5.5	"	3.70	0.35	0.31	9.27	47.0	0.18	0.30

* In 100 gm. soil.

TABLE III(continued)

Range	Plot	pH	Rate of Limestone Application	Exchangeable Cations* Ca	Mg	K	Exchange Capacity*	Base Saturation	Nitrogen	Boron
			lb./acre	me	me	me	me	%	%	ppm
1	1	5.3	2000	5.47	0.15	0.32	10.66	55.7	0.19	0.60
1	8	5.4	"	5.45	0.16	0.30	9.64	61.4	0.20	0.33
1	15	5.2	"	3.91	0.08	0.24	8.82	48.0	0.19	0.25
2	4	6.0	"	6.71	0.14	0.24	9.82	72.2	0.20	0.30
2	10	5.8	"	5.60	0.11	0.22	9.92	59.9	0.18	0.31
2	16	5.6	"	5.75	0.11	0.31	9.58	64.5	0.19	0.25
3	1	5.7	"	4.35	0.39	0.24	9.90	50.4	0.20	0.32
3	9	5.9	"	4.94	0.51	0.29	10.09	56.9	0.19	0.30
3	17	5.5	"	4.06	0.37	0.35	10.00	47.8	0.18	0.28

* In 100 gm. soil.

TABLE III(continued)

Range	Plot	pH	Rate of Limestone Application	Exchangeable Cation* Ca	Mg	K	Exchange Capacity*	Base Saturation	Nitrogen	Boron
			lb./acre	me	me	me	me	%	%	ppm
1	2	5.6	3000	5.96	0.11	0.29	10.04	63.1	0.20	0.56
1	11	5.7	"	6.17	0.14	0.21	9.86	66.0	0.18	0.31
1	17	5.7	"	5.35	0.13	0.22	8.94	63.8	0.18	0.27
2	3	6.3	"	6.94	0.10	0.17	9.74	74.0	0.19	0.25
2	9	6.3	"	7.52	0.14	0.26	10.18	77.9	0.18	0.26
2	15	5.7	"	5.25	0.11	0.24	9.60	58.4	0.19	0.25
3	4	6.0	"	5.33	0.43	0.24	9.88	60.7	0.19	0.31
3	8	6.2	"	6.14	0.59	0.24	9.72	71.8	0.19	0.31
3	13	6.1	"	5.76	0.38	0.20	9.90	64.0	0.19	0.30

* In 100 gm. soil.

corner of the experimental area it is thought that sometime since 1930 they had received an application of borax.

The average values for the chemical analyses of surface soil samples taken in 1930 and in 1948 are presented in Table IV and the effect of limestone on soil reaction and per cent base saturation is illustrated in Figure 4. In respect to the exchangeable magnesium content of the soil there has been a general decrease during the 18 year period. If in calculating the average values for this soil constituent the data from range 3 are omitted, a value of 0.12 milliequivalents is obtained for each of the highest rates of limestone application. Thus the relatively high values in range 3 are responsible for the apparent increase in exchangeable magnesium with increased rates of limestone application. In contrast to exchangeable magnesium the exchangeable potassium status of the soil has improved. That is, the amount of potassium applied as fertilizer together with that released to the exchangeable form by the soil exceeded the amount of potassium removed by the crops plus that lost by leaching. The values given for total nitrogen indicate a decrease in soil organic matter. There is no indication that the various limestone treatments have influenced the increase in exchangeable potassium or the decrease in soil organic matter. Moschler, Obenshain, Cocke and Camper (1949) working with a Sassafras fine sandy loam have reported that 0, 600, 1,200, 1,800, 2,400 and 3,000 pounds per acre of limestone applied every four years over

TABLE IV

AVERAGE VALUES OF CHEMICAL ANALYSIS OF SOILS

Year Sampled	Rate of Limestone Application	pH[2]	Exchangeable Cations[1] Ca	Mg	K	Exchange Capacity[1]	Base Saturation	Nitrogen
	lb./acre		me	me	me	me	%	%
1930(7)		5.16	2.57	0.34	0.16	9.35	33.8	0.22
1948(9)	0	4.92	2.33	0.13	0.27	9.53	28.5	0.19
1948(9)	500	5.11	3.03	0.15	0.26	9.37	36.6	0.19
1948(9)	1000	5.24	3.62	0.20	0.26	9.53	40.6	0.19
1948(9)	1500	5.43	4.30	0.20	0.25	9.64	49.3	0.19
1948(9)	2000	5.53	5.14	0.22	0.28	9.83	57.4	0.19
1948(9)	3000	5.92	6.05	0.24	0.23	9.76	66.6	0.19

[1] In 100 gm. soil.

[2] Obtained by averaging hydrogen ion concentrations.

Figures in brackets refer to the number of values averaged.

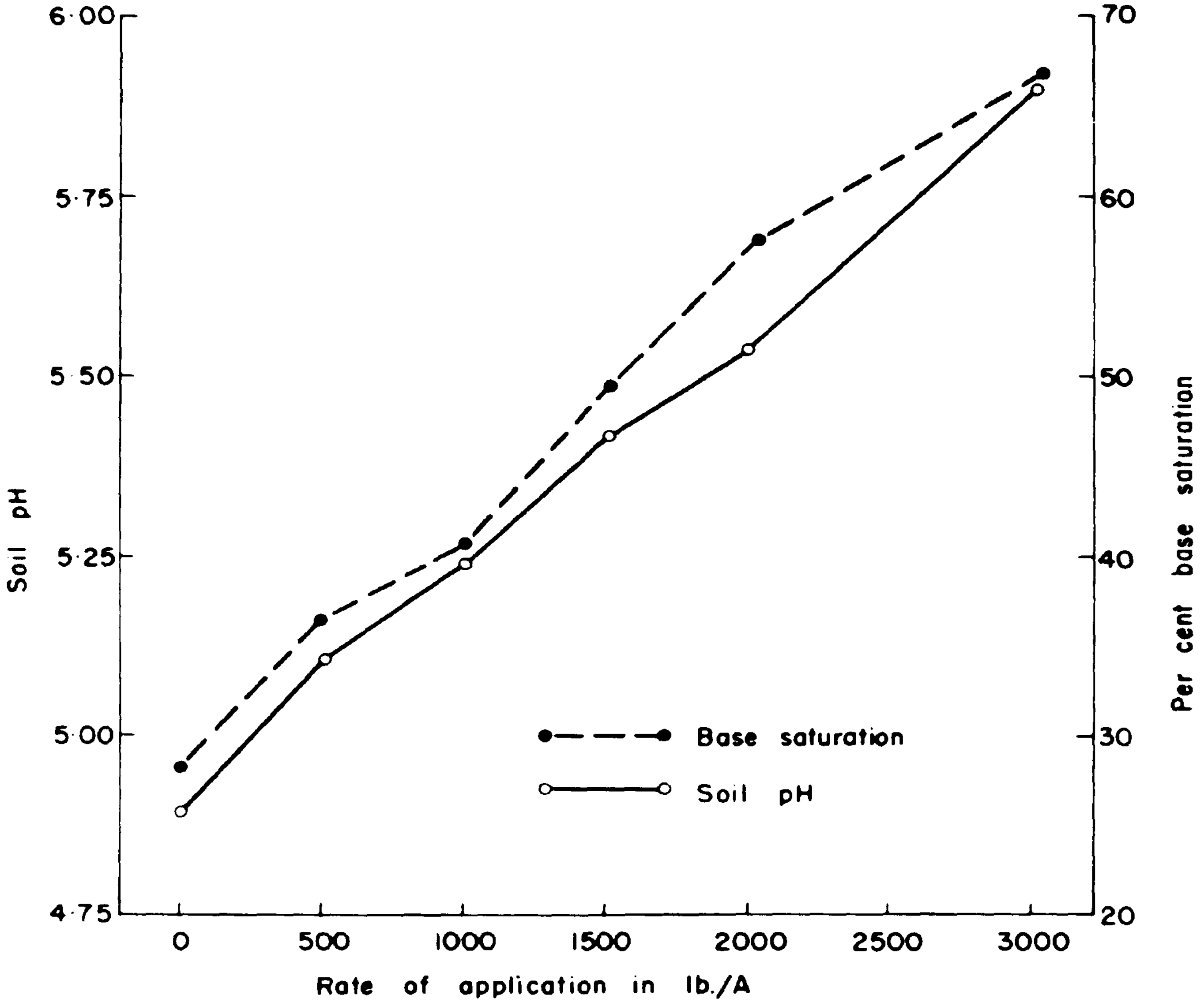


Fig. 4. Effect of limestone on soil pH and per cent base saturation.

a 23 year period had little affect on the potassium status of the soil. Organic matter increased only with the highest rate of limestone.

According to Peech (1941) a change in soil reaction from pH 5 to pH 6 may be expected to increase the total content of exchangeable bases, excluding hydrogen, approximately three times. In the present investigation there has been an increase of approximately two and one-half times. Bear and Toth (1948) have suggested that in an ideal soil 65 per cent of the exchange complex should be occupied by calcium, 10 per cent by magnesium, five per cent by potassium and the remainder by hydrogen. They have further stated that in acid soils used for potato production a two to one ratio of magnesium to potassium is important in order that potassium is not taken up by the plants at the expense of magnesium. In general those plots receiving the highest rate of limestone have approximately 65 per cent of their exchange complex occupied by calcium but only in range 3 does the magnesium to potassium ratio approximate that suggested by Bear and Toth. In view of this it would seem that the use of dolomitic limestone would be preferable in respect to the conditions under which the present field experiment is being conducted.

The water-soluble boron content of seven samples of surface soil taken in 1930 and of comparable samples taken in 1948, as well as other pertinent data, are presented in Table V. With one exception (plot 3 in range 1) there has been

TABLE V

CHANGE IN WATER-SOLUBLE SOIL BORON FROM 1930 TO 1948

Range	Plot	Limestone Applied 1931-1948	pH 1930	pH 1948	Boron 1930	Boron 1948	1948 Boron X 100 / 1930 Boron
		lb./acre			ppm	ppm	%
1	9	0	5.4	4.8	0.49	0.34	69.4
2	13	0	4.9	5.1	0.43	0.30	69.8
2	5	2500	5.2	5.3	0.41	0.30	73.2
3	16	5000	4.7	5.3	0.38	0.26	68.4
1	3	6000	5.3	5.4	0.42	0.53	126.2
3	3	7500	5.2	5.6	0.42	0.30	71.4
3	9	10000	5.2	5.9	0.42	0.30	71.4

a rather consistent decrease in content of water-soluble boron. There is no indication that the magnitude of the decrease has been influenced by the application of limestone and the resulting change in the pH value of the soil. The approximate 30 per cent decrease in the soils from six of the seven plots may be attributed to removal by crops and loss through leaching. Berger (1949) has pointed out that loss of boron by leaching is of particular importance in acid soils. In this connection Kubota, Berger and Truog (1949) as well as Wilson, Lovvorn and Woodhouse (1951) have shown that the lighter the texture of the soil the greater the loss by leaching.

The change from 1930 to 1948 in the water-soluble boron content of the soil in seven plots is shown graphically in Figure 5. The fact that plot 3 in range 1 has a higher content in 1948 than in 1930 lends support to the belief that sometime since the experiment was started this plot, as well as plots 1 and 2 in the same range, received an application of borax.

For comparative purposed the water-soluble boron values for the 1948 samples are presented in Table VI. In view of the boron content of plots 1, 2 and 3 in range 1 the block containing these plots was omitted in calculating the treatment means and also in the analysis of variance which is presented in Table VII.

The results of analysis of subsoil samples taken in 1930 and of comparable samples obtained in 1951 are presented in Table VIII. There is some indication that the limestone treatments are having a slight effect on the subsoil although the changes recorded are generally small and not consistent. It will be noted however that exchangeable magnesium has decreased in all cases while no consistent change has occurred in respect to exchangeable potassium. On the basis of work reported by Blair and Prince (1934) it would seem that the lack of change in the subsoils may be related to the rates of limestone being used at Charlottetown. This view is further substantiated by the work of Brown and Munsell (1938) who found

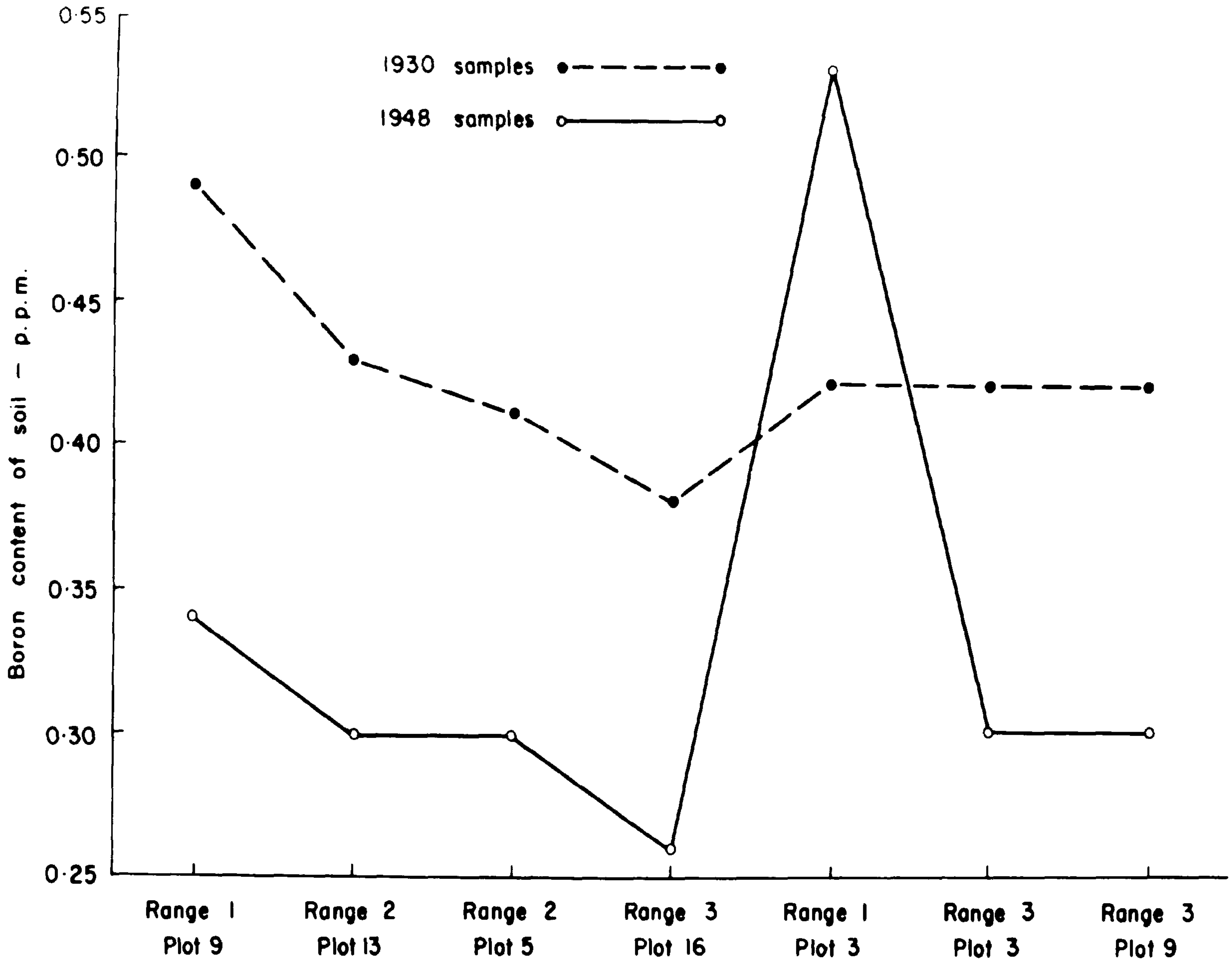


Fig. 5. Water-soluble boron content of soil samples taken in 1930 and in 1948.

TABLE VI

WATER-SOLUBLE BORON CONTENT OF THE 1948 SOIL SAMPLES

Block	Rate of limestone application lb./A						Mean
	0	500	1000	1500	2000	3000	
	ppm.	ppm.	ppm.	ppm.	ppm.	ppm.	
1	0.35	0.30	0.32	0.53	0.60	0.56	0.443
2	0.34	0.32	0.30	0.30	0.33	0.31	0.317
3	0.30	0.27	0.28	0.27	0.25	0.27	0.273
4	0.33	0.28	0.32	0.31	0.30	0.25	0.298
5	0.34	0.29	0.29	0.32	0.31	0.26	0.301
6	0.30	0.26	0.28	0.27	0.25	0.25	0.268
7	0.33	0.33	0.32	0.30	0.32	0.31	0.318
8	0.35	0.29	0.32	0.28	0.30	0.31	0.308
9	0.31	0.28	0.26	0.30	0.28	0.30	0.288
Mean*	0.325	0.290	0.296	0.293	0.293	0.283	

* Block 1 omitted

L.S.D. (P.05), for treatment means = 0.017

L.S.D. (P.05), for block means = 0.019

TABLE VII

ANALYSIS OF VARIANCE OF THE WATER-SOLUBLE BORON CONTENT OF THE 1948 SOIL SAMPLES

Source of Variation	Degrees of Freedom	Mean Square	F Value		
			Obtained	Required	
				P.05	P.01
Blocks	7*	0.00210	7.78	2.29	3.19
Treatments	5	0.00172	6.37	2.49	3.60
Lime vs no lime	1	0.00770	28.52	4.12	7.42
Rates of lime	4	0.00023	0.85	2.64	3.91
Error	35	0.00027			

* Block 1 omitted

TABLE VIII

CHEMICAL ANALYSIS OF SUBSOILS

Range	Plot	Limestone Applied 1931-1951	pH 1930	pH 1951	Exchangeable Cations* Ca 1930	Ca 1951	Mg 1930	Mg 1951	K 1930	K 1951	Exchange Capacity* 1930	Exchange Capacity* 1951	Base Saturation 1930	Base Saturation 1951
		lb./acre			me	me	me	me	me	me	me	me	%	%
1	9	0	5.3	5.3	2.50	1.61	0.23	0.08	0.15	0.17	7.47	6.49	38.3	28.7
2	13	0	5.5	5.3	2.95	1.71	0.15	0.10	0.12	0.14	7.74	6.62	41.6	29.5
2	5	3000	5.0	5.1	1.54	2.25	0.20	0.08	0.15	0.15	4.66	5.57	40.6	44.5
3	16	6000	4.7	5.0	1.27	1.00	0.15	0.10	0.23	0.14	6.52	4.02	25.3	31.1
1	3	7500	5.3	5.3	3.79	2.82	0.25	0.15	0.11	0.15	8.19	7.15	50.7	43.6
3	3	9000	4.9	5.1	1.43	1.93	0.20	0.15	0.17	0.14	7.68	7.79	23.4	28.6
3	9	12000	5.1	5.2	1.30	1.22	0.17	0.10	0.13	0.13	7.89	6.44	20.3	22.5

* In 100 gm. soil.

the time since application and rate of limestone used were important factors affecting the degree and depth to which acidity in the soil was reduced.

2. Yield Data

It was considered that by 1940 soil differences, other than those resulting from the application of limestone, would tend to have levelled off and the effect of the limestone treatments on yields could be better evaluated. In view of this as well as the fact that soil samples were taken from all plots in 1948 it was thought that the yields obtained from 1940 to 1948 inclusive would best reflect the influence of liming. During this period each crop occurred three times on each range.

Potatoes. The potato yields are shown in Table IX. The low yields recorded for 1941, 1943 and 1945 may be partially attributed to unfavorable weather conditions during the growing season. There was an excess of moisture in 1941 and 1943 while in 1945 the rainfall during July and August was approximately half the usual amount.

The analysis of variance, presented in Table X, shows highly significant yield differences between ranges and between years within ranges. The limestone treatments have had no significant effect on yield. While Carolus (1944) found that calcium did not seem to be an important factor in the growth and yield of potatoes, Berger (1948) has reported

TABLE IX

YIELD OF POTATOES
(Expressed as bushels per acre)

Crop Year	Range	Rate of limestone application lb./acre					
		0	500	1000	1500	2000	3000
1940	2	187	149	149	140	149	143
		163	149	148	163	161	161
		136	144	140	149	140	153
1941	3	123	130	127	126	152	101
		119	110	113	103	102	105
		111	104	109	113	98	100
1942	1	190	200	218	220	257	247
		228	238	225	246	274	256
		210	200	202	228	233	251
1943	2	103	97	110	98	106	110
		105	111	119	117	131	118
		117	100	111	107	118	117
1944	3	257	300	310	267	297	299
		313	301	303	283	305	301
		307	260	294	297	232	294

TABLE IX (continued)

YIELD OF POTATOES
(Expressed as bushels per acre)

Crop Year	Range	Rate of limestone application lb./acre 0	500	1000	1500	2000	3000
1945	1	125	120	100	110	100	92
		125	115	120	105	95	105
		125	120	122	120	115	125
1946	2	165	135	127	136	106	106
		149	147	135	125	133	116
		159	128	139	151	137	142
1947	3	230	209	200	232	210	189
		221	233	229	243	216	189
		212	254	208	190	251	211
1948	1	361	375	391	387	375	372
		371	382	392	359	368	321
		242	347	315	362	371	393

TABLE X

ANALYSIS OF VARIANCE OF THE YIELDS OF POTATOES

Source of Variation	Degrees of Freedom	Mean Square	F Value Obtained	F Value Required P.05	F Value Required P.01
Ranges	2	149900.4136	519.72	3.32	5.39
Years within ranges	6	141260.9691	180.50	3.00	4.82
Treatments within ranges	15	349.3062	1.27	2.02	2.69
Treatments	5	53.2247	0.18	2.53	3.70
Lime vs no lime	1	6.0493			
Rates of lime	4	65.0185			
Treatments x ranges	10	498.3469	1.73	2.16	2.98
Replications within ranges	6	475.4691	1.39	2.25	3.12
Years within ranges x Treatments within ranges	30	464.9913			
Years within ranges x Replications within ranges	12	782.6266[1]			
Treatments within ranges x Replications within ranges	30	288.4247[2]			
Years within ranges x Treatments within ranges x Replications within ranges	60	340.9210[3]			

[1] Error mean square for years within ranges.
[2] Error mean square for ranges and treatments within ranges.
[3] Error mean square for replications within ranges.

yield increases from the use of dolomitic limestone. Hawkins, Chucka and Brown (1941) have also reported beneficial results from light applications of dolomitic limestone when a deficiency of magnesium caused reduced yields.

Reports on the potato crops show the incidence of scab to be increasing with plots receiving the higher rates of limestone being the most seriously affected. Cook and Nugent (1939) found a relationship between soil reaction and scab and concluded that calcium compounds affect scab only to the extent that they change soil reaction. Nelson and Brady (1943) grew potatoes in the greenhouse and reported that dolomitic limestone placed at a 10 inch depth increased yield but did not increase scab. When the limestone was mixed with the surface soil scab infection was increased.

Barley. The yield data for barley are presented in Table XI and the analysis of variance of the data is given in Table XII. Differences in yield between ranges and in years within the same range are highly significant. There is also a significant effect from the application of limestone. Both Ahlgren (1949) and Klages (1949) have pointed out that barley is sensitive to soil acidity while Webber, Morwick, Heeg, Thomas and Richards (1952) have given 6.5 to 7.8 as a favorable pH range for this crop.

Field notes show that in 1943 and also in 1945 the growth in certain plots was apparently retarded by soil moisture

TABLE XI

YIELD OF BARLEY
(Expressed as bushels per acre)

Crop Year	Range	Rate of limestone application lb./acre 0	500	1000	1500	2000	3000
1940	1	35.0	32.5	41.9	45.0	37.5	40.0
		32.5	36.9	38.7	43.7	37.5	42.5
		23.1	36.9	38.1	33.7	33.7	43.7
1941	2	21.2	13.7	18.7	25.0	16.2	16.2
		18.7	30.0	26.2	23.7	15.0	13.7
		18.7	15.0	12.5	21.2	15.0	21.2
1942	3	42.5	47.5	56.2	42.5	42.5	38.7
		46.2	48.7	35.0	52.5	47.5	55.0
		17.5	32.5	32.5	42.5	40.0	47.5
1943	1	25.0	31.2	36.2	33.7	35.0	40.0
		36.2	40.0	36.2	31.2	33.7	36.2
		26.2	12.5	15.0	35.0	30.0	21.2
1944	2	29.2	36.1	37.5	41.7	43.1	36.1
		44.5	48.6	50.0	36.1	47.2	45.9
		37.5	32.0	34.7	44.5	43.8	50.0

TABLE XI (continued)

YIELDS OF BARLEY
(Expressed as bushels per acre)

Crop Year	Range	Rate of limestone application lb./acre 0	500	1000	1500	2000	3000
1945	3	22.2	23.6	26.4	26.4	32.0	29.2
		29.2	20.9	34.7	32.0	30.6	27.8
		5.6	19.5	18.1	22.2	18.1	29.2
1946	1	26.4	27.8	30.6	36.1	27.8	45.9
		40.3	38.9	40.3	37.5	33.4	44.5
		26.4	29.2	38.9	36.1	40.3	41.7
1947	2	18.1	26.4	26.4	32.0	27.8	30.6
		27.8	30.6	37.5	29.2	33.4	29.2
		26.4	23.6	26.4	30.6	27.8	30.6
1948	3	23.6	29.2	33.4	29.2	41.7	32.0
		41.7	40.3	30.6	40.3	34.7	33.4
		19.5	33.4	38.9	37.5	30.6	37.5

TABLE XII

ANALYSIS OF VARIANCE OF THE YIELDS OF BARLEY

Source of Variation	Degrees of Freedom	Mean Square	F Value Obtained	Required P.05	Required P.01
Ranges	2	399.7420	7.87	3.32	5.39
Years within ranges	6	1258.4130	19.74	3.00	4.82
Treatments within ranges	15	76.2876	1.50	2.02	2.69
Treatments	5	195.2060	3.84	2.53	3.70
Lime vs no lime	1	639.2892	12.58	4.17	7.56
Rates of lime	4	84.1852	1.66	2.69	4.02
Treatments x ranges	10	16.8283			
Replications within ranges	6	227.5660	10.86	2.25	3.12
Years within ranges x Treatments within ranges	30	19.1619			
Years within ranges x Replications within ranges	12	63.7505[1]			
Treatments within ranges x Replications within ranges	30	50.8080[2]			
Years within ranges x Treatments within ranges x Replications within ranges	60	20.9605[3]			

[1] Error mean square for years within ranges.
[2] Error mean square for ranges and treatments within ranges.
[3] Error mean for replications within ranges.

conditions. This could be partially responsible for the fact that the analysis of variance shows a highly significant difference between replications within ranges. Wilson (1948) has stated that barley does not do well on wet, poorly drained sandy soils.

Although oats are the most important grain crop in the Maritime Provinces, barley production is increasing. According to Shuh (1952) the barley acreage in Prince Edward Island from 1940 to 1949 was approximately two and one-third times as great as it was during the preceding 10 year period. Cowan (1952) has drawn attention to the fact that the variety most commonly grown in the Maritimes is Charlottetown 80 which originated from a selection made at the Dominion Experimental Station at Charlottetown, Prince Edward Island.

Clover. The clover yields, presented in Table XIII, represent the weight of all plant growth on each plot. Field notes however, taken during the growing season, show that considerable and rather consistent differences existed in the plots each year with respect to what per cent of the total growth was clover. In the check plots, clover seldom accounted for more than 10 per cent of all growth with the remainder being volunteer red top, daisies and weeds. In the plots, receiving the highest rate of limestone, clover represented at least 75 per cent of all growth. Thus it would appear that the limestone treatments have had more influence on this crop than is indicated by the reported yields.

TABLE XIII

YIELD OF CLOVER
(Expressed as tons per acre on an air-dry basis)

Crop Year	Range	Rate of limestone application lb./acre 0	500	1000	1500	2000	3000
1940	3	0.439	0.695	1.136	0.653	0.702	1.044
		0.951	0.533	0.978	1.334	1.022	1.289
		0.438	0.301	0.371	0.451	0.556	1.164
1941	1	0.537	0.587	0.893	1.167	1.287	1.293
		0.704	0.745	1.439	1.307	1.246	1.142
		0.369	0.370	0.449	0.925	0.487	0.767
1942	2	1.075	1.357	1.638	1.507	1.645	1.401
		1.048	1.002	1.383	1.486	1.579	1.604
		0.577	0.665	0.616	0.798	1.008	1.420
1943	3	1.437	1.147	1.620	1.673	2.179	1.985
		0.701	0.714	1.173	0.907	0.775	1.238
		1.134	1.022	1.093	0.824	1.451	1.183
1944	1	0.397	1.131	2.163	1.836	1.877	1.921
		0.429	1.121	1.847	2.093	2.021	1.616
		0.381	1.024	0.929	1.825	2.493	1.817

TABLE XIII (continued)

YIELD OF CLOVER
(Expressed as tons per acre on an air-dry basis)

Crop Year	Range	Rate of limestone application lb./acre 0	500	1000	1500	2000	3000
1945	2	1.010	1.295	1.694	1.163	1.661	1.753
		1.033	1.101	1.257	1.617	1.423	1.637
		0.693	0.724	0.873	1.351	1.245	1.407
1946	3	0.533	0.927	1.253	1.345	1.313	1.667
		0.325	0.858	1.402	1.200	1.073	1.398
		0.507	0.796	0.869	1.086	1.257	1.451
1947	1	0.336	0.618	0.699	0.792	1.057	1.203
		0.407	0.671	1.072	0.901	1.142	1.287
		0.270	0.501	1.101	0.778	1.028	1.501
1948	2	2.506	3.127	3.007	3.245	3.003	3.277
		3.233	2.577	2.903	2.936	2.543	3.061
		2.088	2.247	2.763	3.068	2.701	2.963

It will be noted that the 1948 yields are much greater than those obtained in any other year. While there is no apparent reason for this, it may be stated that exceptionally high clover yields were reported throughout Prince Edward Island in 1948.

The analysis of variance of the clover yields, presented in Table XIV, shows differences between ranges, between years within ranges and between treatments to be highly significant.

The relation of soil acidity to the growth of red clover has been discussed by Bryan (1923) while Snider (1946) has pointed out that, in addition to lime, adequate amounts of phosphorus and potassium are necessary for satisfactory growth. According to Ahlgren (1949) a pH range of 6.0 to 6.5 is satisfactory for this crop which is best adapted to soils of fairly heavy texture that are well supplied with organic matter and lime.

Average yields. The average yields for all crops are presented in Table XV and the effect of the various rates of limestone on the yields of barley and clover is illustrated in Figure 6. While there is no apparent reason why the barley yields decreased with the application of two thousand pounds of limestone, there is an indication that the yields tend to level off with the higher rates. This tendency is much less marked in the case of the clover crop.

TABLE XIV

ANALYSIS OF VARIANCE OF THE YIELDS OF CLOVER

Source of Variation	Degrees of Freedom		Mean Square	F Value Obtained	Required P.05	Required P.01
Ranges	2		9.6136	19.06	3.32	5.39
Years within ranges	6		6.2383	32.19	3.00	4.82
Treatments within ranges	15		0.8062	1.60	2.02	2.69
Treatments	5		2.1589	4.28	2.53	3.70
Lime vs no lime		1	5.7790	11.46	4.17	7.56
Rates of lime		4	1.2539	2.49	2.69	4.02
Treatments x ranges	10		0.1298			
Replications within ranges	6		0.5868	1.24	2.25	3.12
Years within ranges x Treatments within ranges	30		0.9296			
Years within ranges x Replications within ranges	12		0.1938[1]			
Treatments within ranges x Replications within ranges	30		0.5043[2]			
Years within ranges x Treatments within ranges x Replications within ranges	60		0.4713[3]			

[1] Error mean square for years within ranges.
[2] Error mean square for ranges and treatments within ranges.
[3] Error mean square for replications within ranges.

TABLE XV

AVERAGE YIELDS OF POTATOES, BARLEY AND CLOVER
FROM 1940 TO 1948 INCLUSIVE

Crop		Rate of limestone application lb./acre					
		0	500	1000	1500	2000	3000
Potatoes	(bu./A)	191	191	191	192	194	190
Barley	(bu./A)	28.2	31.0	33.0	34.9	33.2	35.5
Clover	(T/A)	0.873	1.032	1.356	1.425	1.473	1.611

L.S.D. (P.05), for barley = 3.96

L.S.D. (P.05), for clover = 0.395

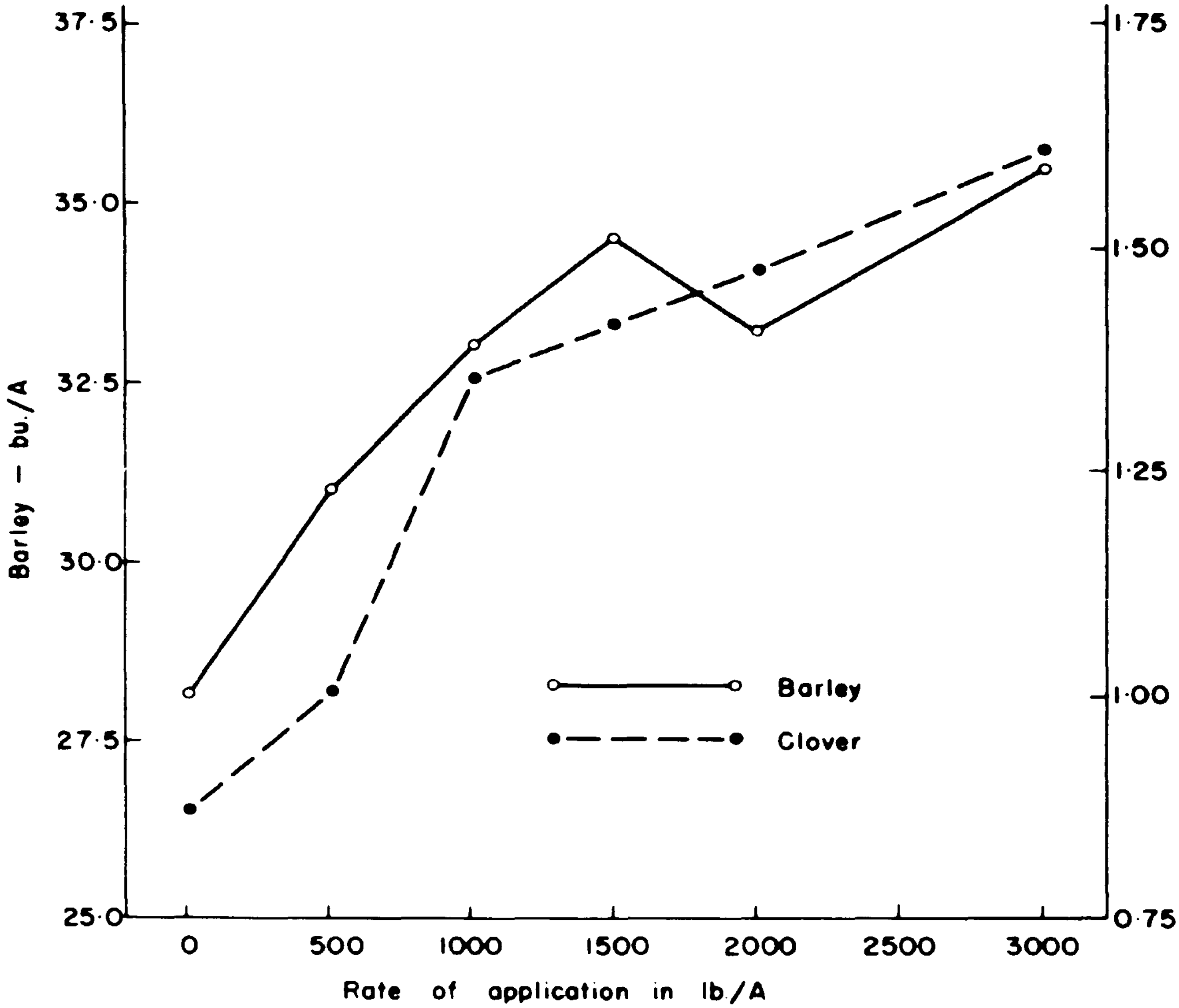


Fig. 6. Effect of limestone on yield of barley and clover.

B. Greenhouse Studies on the Effect of Limestone on the Availability of Soil Boron

Crop yields. Yield data for two ladino clover crops are presented in Table XVI.

It will be noted that the average yields for similar treatments were consistently lower in 1951-52 than in 1950-51. The greatest differences between years occurred in the yields from check cultures and those which received limestone without fertilizer. In terms of the 1950-51 yields, those of the following year were less by 61.9 and 57.0 per cent respectively. In the case of the 0-10-10 treatment the decrease was 27.3 per cent and where limestone and 0-10-10 were applied together there was a 14.7 per cent decrease. In the second crop year visual symptoms of potassium deficiency were observed on the plants which did not receive potash fertilizer.

The analysis of variance of the two clover crops is given in Table XVII. The various soil treatments produced no significant yield differences in the first crop year. In the following year, however, the yield obtained from the application of limestone together with the 0-10-10 fertilizer was significantly greater than with no treatment or with limestone alone.

According to Giddens and Toth (1951) the ratios of cations in the exchange complex of the soil may affect the growth of ladino clover. They also found indications that calcium should be the dominant cation. On the basis of field, greenhouse and

TABLE XVI

YIELD OF LADINO CLOVER PER POT
(Air-dry weight in grams)

Crop Year	Treatment	Replications 1	2	3	Average
1950-51	Check	28.50	31.20	27.00	28.90
	Limestone 2T/A	27.20	32.80	29.80	29.93
	0-10-10 800 lb./A	29.70	31.50	37.80	33.00
	Limestone 2 T/A & 0-10-10 800 lb./A	37.80	34.40	35.30	35.83
1951-52	Check	15.45	7.15	10.40	11.00
	Limestone 1.5 T/A	15.80	10.95	14.90	13.88
	0-10-10 800 lb./A	24.15	20.20	27.65	24.00
	Limestone 1.5 T/A & 0-10-10 800 lb./A	29.50	38.95	23.30	30.58

No significant difference between treatment means for 1950-51 crop.

L.S.D. (P.05), treatment means for 1951-52 crop = 13.93

TABLE XVII

ANALYSIS OF VARIANCE OF THE YIELD OF LADINO CLOVER

1950-51 Crop

Source of Variation	Degrees of Freedom	Mean Square	F Value Obtained	F Value Required P.05	F Value Required P.01
Replications	2	3.7425			
Treatments	3	29.5500	2.97	4.76	9.78
Error	6	9.9441			

1951-52 Crop

Sources of Variation	Degrees of Freedom	Mean Square	F Value Obtained	F Value Required P.05	F Value Required P.01
Replications	2	13.9313			
Treatments	3	251.9052	8.76	4.76	9.78
Error	6	28.7401			

laboratory studies Stewart and Bear (1951) have reported ladino clover to have high mineral requirements with adequate supplies of potassium being essential for sustained productivity. Boulet and Choiniere (1953), reporting on the growth of ladino in the Province of Quebec, have also shown the importance of potassium in relation to this crop.

Boron content of soils and crops. The average yields of ladino clover together with the boron content of composite plant and soil samples is illustrated in Figure 7.

In terms of the check, the application of limestone alone resulted in a 31.6 per cent decrease in the water-soluble boron content of the soil during the 1950-51 crop year. When limestone was applied with an 0-10-10 fertilizer the decrease, in terms of soil receiving fertilizer alone, was 30.6 per cent. The decreases for the 1951-52 crop year, calculated in a comparable manner, were 54.8 and 53.1 per cent respectively. Thus the application of limestone, either alone or in combination with an 0-10-10 fertilizer, decreased the water-soluble boron content of the soil. The magnitude of the decrease appeared to depend on the amount of limestone applied and the extent to which the pH value of the soil was changed.

On the basis of yield and boron content the 1950-51 clover crop obtained a total of 2.108 milligrams of boron from soil receiving limestone as against 2.216 milligrams where no limestone was applied. The comparable amounts for the 1951-52 crop were 0.672 and 1.278 milligrams. Thus the availability of the

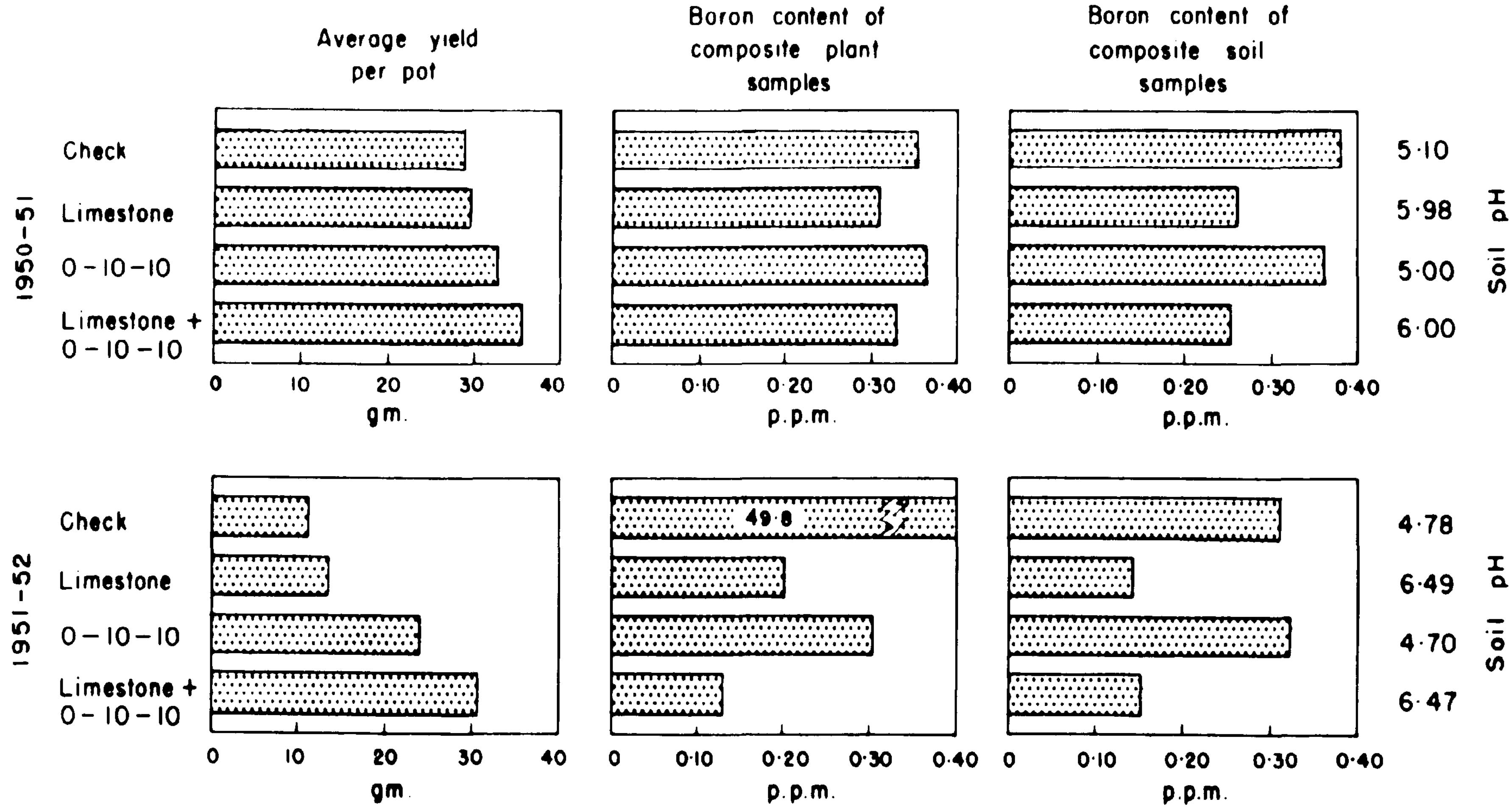


Fig. 7. Effect of soil treatments on yield and boron content of ladino clover and on the pH value and water-soluble boron content of the soil.

soil boron, in terms of the amounts taken up by the crops, was reduced by the application of limestone.

Using the values obtained in the two crop years a correlation coefficient of +0.76 was found between the water-soluble boron content of the soil and the boron content of the ladino clover. This figure was significant at the 5 per cent level.

According to Dregne and Powers (1942) ladino clover has shown indifferent response to boron in Oregon. Munsell and Brown (1943) have reported that this legume, grown on a soil containing 0.50 parts per million of "available" boron, had a boron content of 28 and 30 parts per million. When borax was applied at the rate of 20 pounds per acre, the boron content of the clover was 30 and 32 parts per million respectively. These investigators have suggested that ladino is comparable to alfalfa in respect to boron content. Stinson (1953) has given 0.30 parts per million of water-soluble boron as a critical level for the growth of alfalfa on coarse textured sandy soils. He has also considered that, in respect to other legumes, alfalfa is especially sensitive to a shortage of "available" boron. Data given by Rogers (1947) show the critical level of boron in alfalfa, as reported by various investigators, exhibits considerable variation. A similar situation may be expected to exist in respect to ladino clover and the critical level in the plant may show some variation with different growing conditions.

Calcium-boron ratios. The effect of the soil treatments on the calcium and boron content of the ladino clover is shown in Table XVIII.

In both crop years the clover grown on soils receiving limestone alone had a higher calcium content than the clover grown on the checks. A similar situation existed between the crops grown with limestone and fertilizer and those receiving fertilizer alone. The increase in calcium content was, however, relatively less than the decrease in boron content that occurred in the plants grown on the limed soils. This was especially true in the second crop year.

The relative amounts of calcium and boron in the two crops are reflected in the calcium-boron ratios. Although in the first crop year the differences were comparatively small the highest ratios occurred in plants treated with limestone. In the second crop year there were very marked differences in the ratios found in clover grown on limed and unlimed soils. There were not, however, any visual symptoms of boron deficiency observed during either crop year. It is possible that if the plants had been allowed to reach maturity visual symptoms of deficiency might have been evident.

Stewart and Bear (1951) have pointed out that, while in cases of severe boron deficiency, ladino clover leaves turn red and then yellow, deficiency symptoms for this crop are

TABLE XVIII

EFFECT OF SOIL TREATMENTS ON THE CALCIUM AND BORON CONTENT OF LADINO CLOVER

(Composite samples from three replications, air-dry basis)

Crop Year	Soil Treatment	pH	Ladino Clover Ca	Ladino Clover B	Ladino Clover Ca:B Ratio
			ppm.	ppm.	
1950-51	Check	5.10	21400	35.8	598:1
	Limestone	5.90	22400	31.0	723:1
	0-10-10	5.00	20600	36.4	566:1
	Limestone & 0-10-10	6.00	22400	33.0	679:1
1951-52	Check	4.78	27800	49.8	558:1
	Limestone	6.49	28900	20.1	1438:1
	0-10-10	4.70	24000	30.4	789:1
	Limestone & 0-10-10	6.47	26600	12.8	2078:1

not easily recognized in the field. From data given by these investigators an average calcium-boron ratio for ladino clover grown in New Jersey was calculated to be 272 to 1. The difference between this calcium-boron ratio and those reported in the present investigation was chiefly due to differences in the boron rather than the calcium content of the clover.

C. Laboratory Studies

1. Effect of Calcium Carbonate, Gypsum and Magnesium Carbonate on the Water-Soluble Boron Content of Soil

The effect of calcium carbonate, gypsum and magnesium carbonate on the water-soluble boron content of soil is illustrated in Figure 8.

Calcium carbonate. The application of increasing rates of calcium carbonate resulted in decreased contents of water-soluble boron. The decreases in boron, which were consistent with the increased rates of calcium carbonate and increased soil pH values, ranged from 6.3 per cent with a one ton application to 59.4 per cent with eight tons. A highly significant correlation coefficient of -0.98 existed between the amount of calcium applied and the water-soluble boron content of the treated soils.

Gypsum. The gypsum treatments, while accompanied by slight increases in soil acidity, resulted in negligible changes in water-soluble boron. The greatest decrease in boron content was 5.9 per cent and occurred with an intermediate rate of gypsum. There was no change with the smallest application and in three instances the decrease was only 2.9 per cent. The correlation coefficient between the amount of calcium applied and the water-soluble boron content of the treated soils was -0.56. This was not significant.

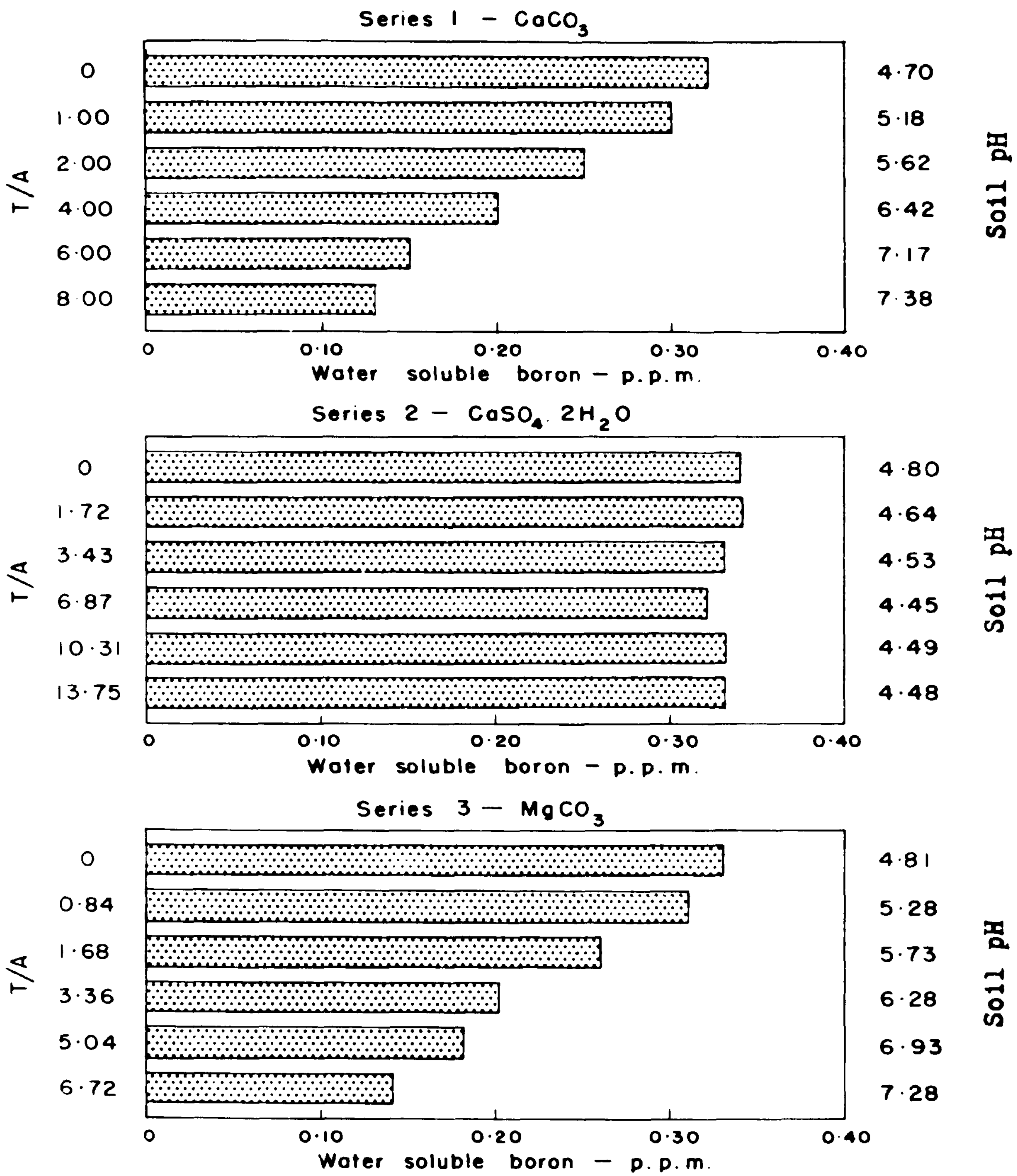


Fig. 8. Effect of $CaCO_3$, $CaSO_4.2H_2O$ and $MgCO_3$ on the water-soluble boron content of soil.

Magnesium carbonate. The decreases in water-soluble boron, which occurred with applications of magnesium carbonate, were almost identical with those resulting from the use of calcium carbonate. The range in pH values was similar in both instances. There was a 6.1 per cent reduction in boron content with the lowest rate of magnesium carbonate and a 57.6 per cent decrease with the highest rate. A highly significant correlation coefficient of -0.98 was found between the amount of magnesium applied and the water-soluble boron in the treated soil.

2. Effect of Manure and Alfalfa, Alone and in Combination with Calcium Carbonate, on the Water-Soluble Boron Content of Soil

The effect of increasing amounts of manure and alfalfa, both alone and in combination with increasing amounts of calcium carbonate, on the water-soluble boron content of soil is illustrated in Figure 9.

Manure. The application of increasing amounts of manure increased the water-soluble boron content of the soil although acidity was somewhat reduced. The increases in boron, while small with the lower rates of manure, were consistent and ranged from 3.1 to 40.6 per cent. A highly significant correlation coefficient of +0.99 existed between the rates of manure applied and the water-soluble boron content of the treated soils.

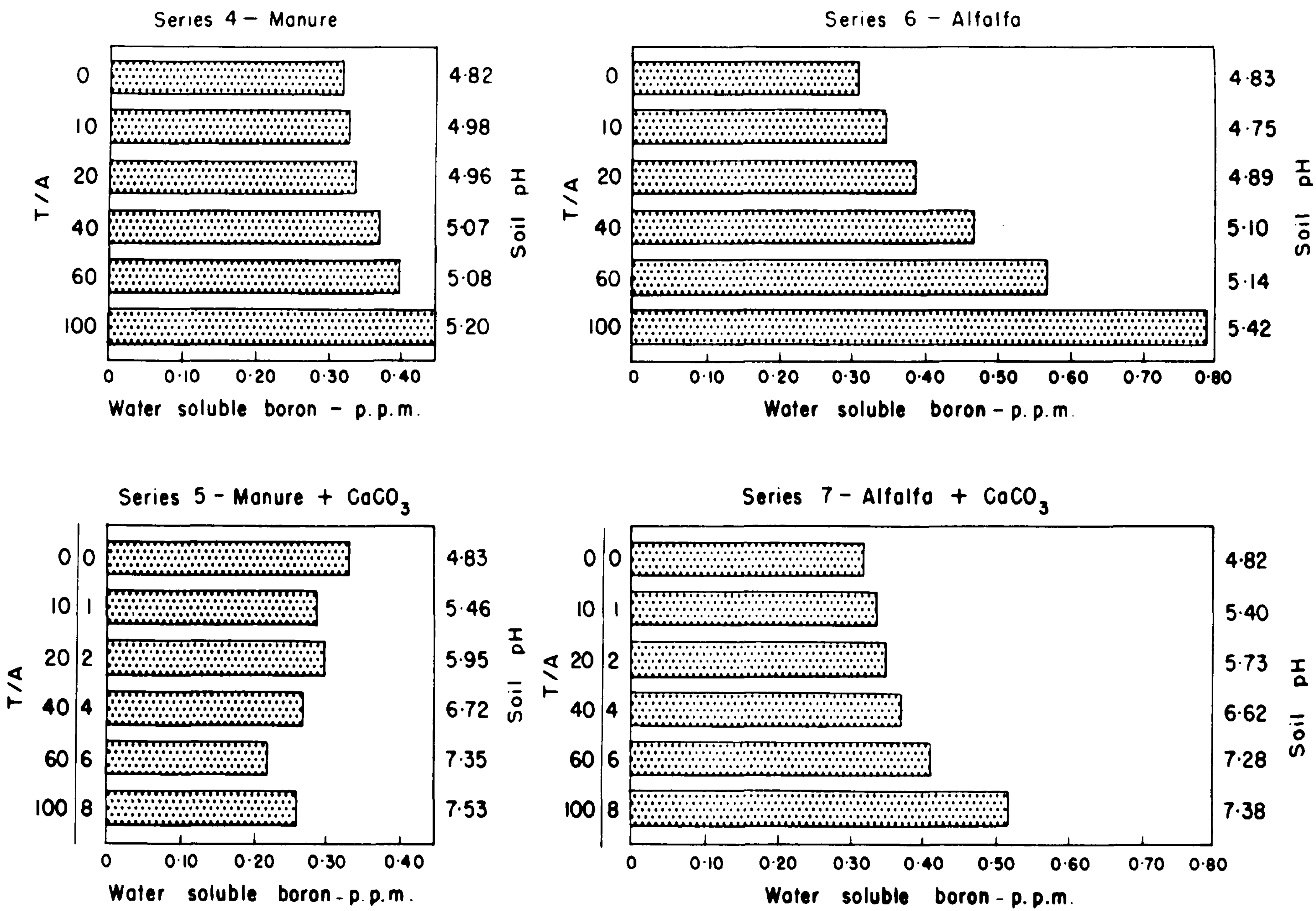


Fig. 9. Effect of manure and alfalfa alone and in combination with $CaCO_3$, on the water-soluble boron content of soil.

Manure and calcium carbonate. The water-soluble boron content of the soil was decreased by applications of manure and calcium carbonate. The decreases, calculated in terms of soil receiving similar manure treatments, ranged from 11.8 to 45.0 per cent and showed some inconsistencies in respect to the rates of calcium carbonate applied. It was found that a significant correlation coefficient of -0.87 existed between the pH value and water-soluble boron content of the treated soils.

Alfalfa. The consistent increases in water-soluble boron content of the soil that occurred with this treatment ranged from 12.9 to 154.8 per cent. The larger additions of alfalfa also resulted in appreciable decreases in soil acidity. A highly significant correlation coefficient of +0.99 was found between the rate of alfalfa applied and the water-soluble boron content of the treated soils.

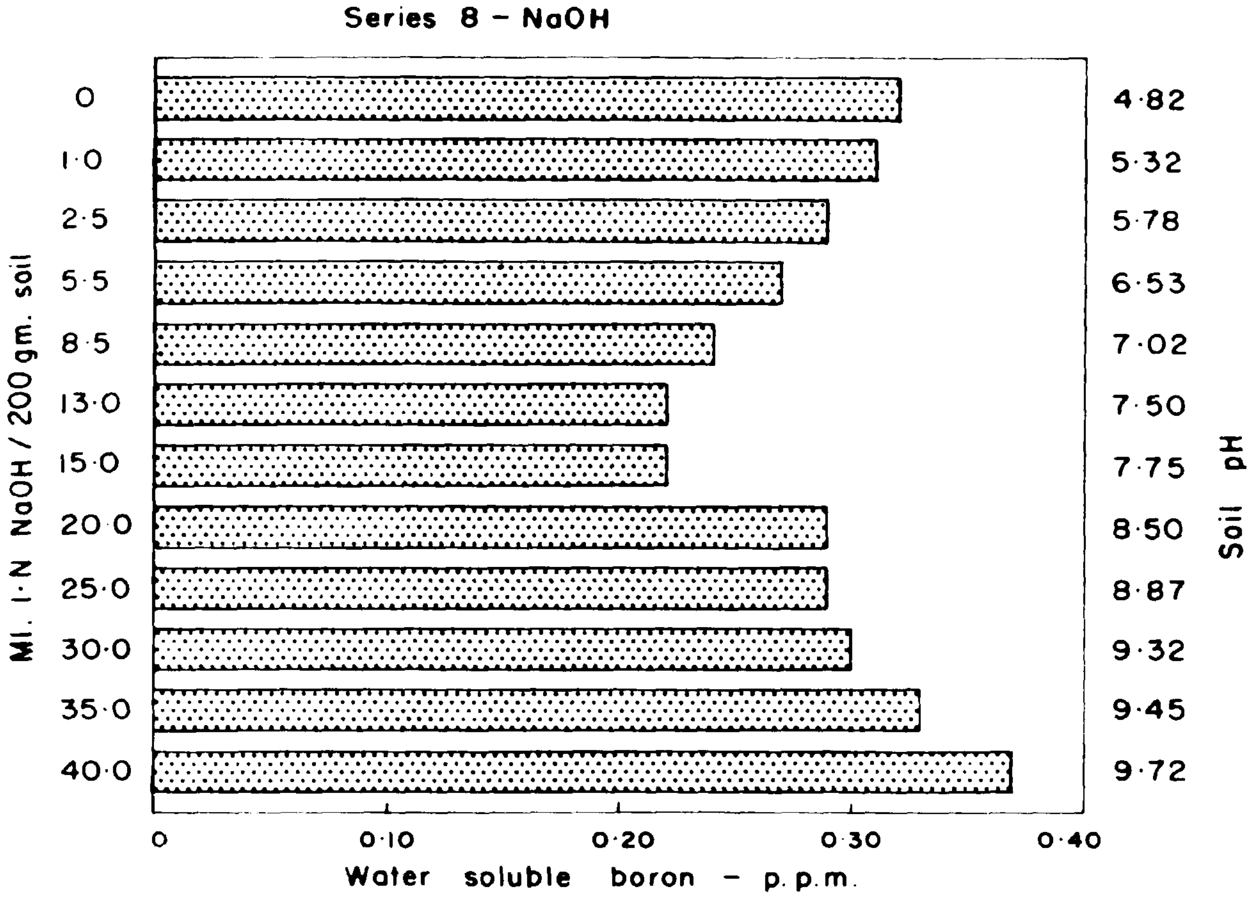
Alfalfa and calcium carbonate. In no case did the combined alfalfa and calcium carbonate treatments reduce the water-soluble boron of the treated soils to the level of the check. However, in terms of soil receiving similar amounts of alfalfa, the addition of calcium carbonate was accompanied by reductions in boron ranging from 2.9 to 34.2 per cent. A significant correlation coefficient of +0.84 existed between the pH value and water-soluble boron content of the treated soils.

3. Effect of Sodium Hydroxide, Alone and in Combination with Calcium Carbonate, on the Water-Soluble Boron Content of Soil

The effect of increasing amounts of sodium hydroxide and of a constant amount of sodium hydroxide in combination with increasing amounts of calcium carbonate, on the water-soluble boron content of soil is illustrated in Figure 10.

Sodium hydroxide. Increasing amounts of sodium hydroxide resulted in decreased contents of water-soluble boron until the pH of the soil reached approximately 8.0. From this point, up to a pH value of 9.72, the boron content of the soil increased. At pH values of 7.50 and 7.75 decreases in boron content amounted to 31.5 per cent. When the pH value of the soil was 9.72 the increase, in terms of the check, was 15.6 per cent. The correlation coefficient between the pH value and water-soluble boron content of the treated soils was +0.22. This was not significant.

Sodium hydroxide and calcium carbonate. The application of increasing amounts of calcium carbonate, to a soil previously treated with sodium hydroxide, resulted in decreased contents of water-soluble boron. The decreases, which showed some inconsistencies in respect to the amounts of calcium carbonate applied, ranged from 3.4 to 24.1 per cent and were accompanied by increased pH values. A significant correlation coefficient of -0.88 existed between the pH value and water-soluble boron content of the treated soils. The correlation



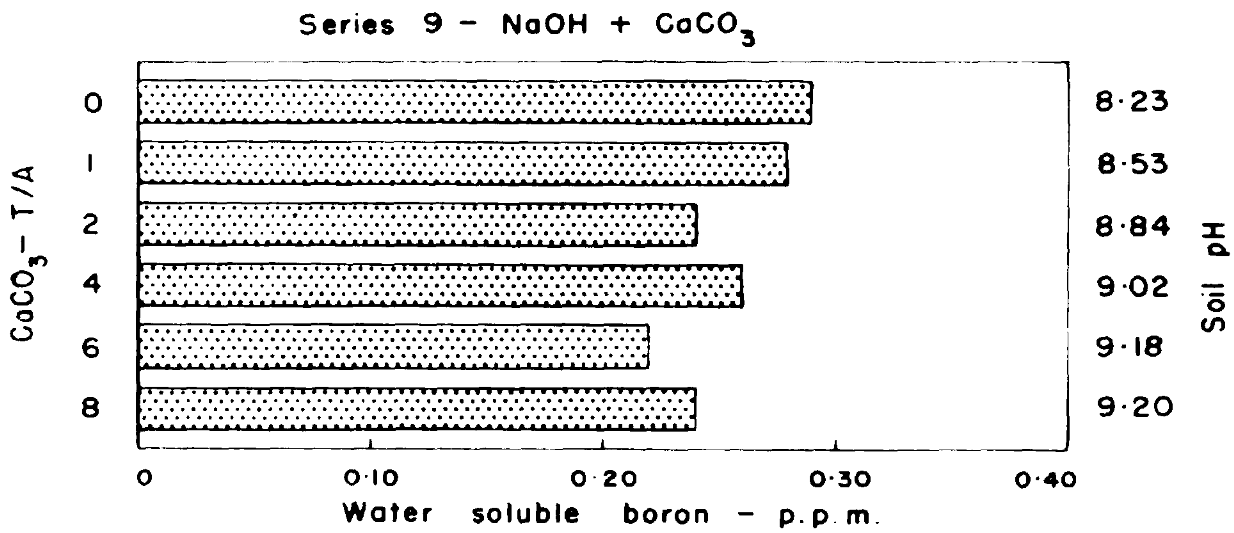


Fig. 10. Effect of NaOH alone and in combination with $CaCO_3$ on the water-soluble boron content of soil.

coefficient of -0.77, found between the amount of calcium applied and the water-soluble boron in the treated soils, failed to reach significance.

4. The Water-Soluble Boron Content of Soil

The decreases that occurred in the concentration of water-soluble boron with applications of calcium carbonate, either alone or in combination with manure or alfalfa, are shown in Table XIX. The values given for the original soil were obtained from series 1 while those for the manured soil represent the differences between series 4 and series 5. In the case of the alfalfa treated soil differences between series 6 and 7 are given. It will be noted that any one rate of calcium carbonate tended to result in the same decrease irrespective of the water-soluble boron content of the soil.

The analysis of variance, presented in Table XX, shows that the application of calcium carbonate has resulted in highly significant decreases in the water-soluble boron content of soil. Although Drake, Sieling and Scarseth (1941) found the addition of lime had no effect on the water-soluble boron content of a silt loam soil, other investigators, including Cook and Millar (1939), Muhr (1940), Schaller (1948) and Davis (1949) have reported decreased boron availability with liming.

The results of the present investigation, in respect to the influence of gypsum on boron availability, are in agreement

TABLE XIX

DECREASE IN THE WATER-SOLUBLE BORON CONTENT OF SOIL DUE TO THE APPLICATION OF CALCIUM CARBONATE

Soils	Calcium carbonate T/A					Mean
	1	2	4	6	8	
	ppm.	ppm.	ppm.	ppm.	ppm.	
Original	0.02	0.07	0.12	0.17	0.19	0.114
Original + manure	0.04	0.04	0.10	0.18	0.19	0.110
Original + alfalfa	0.01	0.04	0.10	0.16	0.27	0.116
Mean	0.023	0.050	0.107	0.170	0.217	

L.S.D. (P.05), for treatment means = 0.050

TABLE XX

ANALYSIS OF VARIANCE OF THE DECREASE IN THE WATER-SOLUBLE BORON CONTENT OF SOIL DUE TO THE APPLICATION OF CALCIUM CARBONATE

Source of Variation	Degrees of Freedom	Mean Square	F Value		
			Obtained	Required	
				P.05	P.01
Soils	2	0.000047			
Treatments	4	0.019534	27.40	3.84	7.01
Error	8	0.000713			

with findings reported by Truninger (1944), Wolf (1940) and Smith (1949).

Parks and Shaw (1941), using pure chemical systems under laboratory conditions, have shown that boron may be precipitated in combination with various ions including silicon and aluminium. Also the boron content of the precipitates tended to be increased by the presence of calcium and at pH values of 7 and above the boron in the precipitates was completely insoluble in hot water. Thus pH differences may account for the results obtained in the present investigation when equivalent amounts of calcium were applied as calcium carbonate and as gypsum. A further indication that pH plays an important part in boron fixation is provided by the results obtained with $MgCO_3$. Midgley and Dunklee (1939) have reported calcium and magnesium carbonates to be equally effective in causing the fixation of boric acid. According to Olson and Berger (1946) the alkalinity produced by bases has more influence on boron fixation than do the cations of the bases.

Differences in the form in which boron exists in manure and alfalfa, in the relative rates of decomposition of the two materials and in their boron content could be responsible for the fact that additions of alfalfa produced the greater increases in the water-soluble boron content of soil. Olson and Berger (1946) have observed that the oxidation of organic matter resulted in and increase in available boron. Brown and King (1939) have reported that boron deficiency in alfalfa appeared to have been somewhat reduced by the application of manure. In respect to boron availability Berger and Truog (1945) have indicated the final effect of organic matter is less than that of pH.

The results obtained in series 1 and series 8 show that at similar pH values calcium carbonate produced a greater decrease in water-soluble boron than did sodium hydroxide. Cooper (1947) has pointed out that sodium tetraborate is considerably more soluble than calcium metaborate. He has also suggested that liming may decrease boron availability by the formation of relatively insoluble calcium borate. According to Colwell and Cummings (1944) there is a fundamental difference in the behavior of aqueous solutions of calcium and sodium metaborates with the former dissolving very slowly. Thus the nature of the cation associated with a change in the pH value of soil may have a bearing on boron availability. Another factor in the case of soils treated with sodium hydroxide is the amount of organic matter subsequently brought into solution by extraction with boiling water. Since boron exists in both organic and inorganic forms the presence of sodium hydroxide could conceivably result in the release of boron held in organic form. This would not be the case with a weak base such as calcium hydroxide.

The addition of calcium to a soil previously treated with sodium hydroxide caused some decreases in content of water-soluble boron. The reductions were, however, considerably less than occurred with calcium carbonate treatments alone. While the resulting soil pH values differed considerably the presence of sodium ions apparently reduced the effect of the calcium carbonate. According to Cook and Millar (1939) and Muhr (1940) sodium carbonate was ineffective in preventing boron toxicity in soybeans. Wolf (1940) has also observed that the nature of the cation employed in changing the pH of a soil has an important bearing on the availability of soil boron.

VII SUMMARY

Field, greenhouse and laboratory experiments were used to study the results of liming a strongly acid soil and the effect of certain other treatments on its content of water-soluble boron. The soil investigated, a Charlottetown fine sandy loam, is one of the best and most extensive agricultural soils on Prince Edward Island.

The field experiment, located at the Dominion Experimental Station, Charlottetown, Prince Edward Island, was started in 1931. It consisted of a three year rotation of potatoes, barley and clover. Prior to 1942 a 4-8-6 fertilizer at 1,200 pounds per acre was used for the potato crop and limestone treatments of 0, 500, 1,000, 1,500, 2,000 and 3,000 pounds per acre were applied every sixth year. Since 1942 limestone has been applied every third year, a 4-8-10 fertilizer has been used for the potato crop and the barley has received 300 pounds per acre of a 2-12-10 fertilizer.

In 1948 composite soil samples, taken at the 0 to 6 inch depth, were obtained from each plot in the experiment. Chemical determinations made on these, as well as on seven samples taken in 1930, included pH value, exchangeable bases, base exchange capacity, total nitrogen and water-soluble boron.

In 1951 seven subsoil samples, taken at the 6 to 12 inch depth, were taken from plots where similar samples had been taken in 1930. With the exception of total nitrogen and water-soluble boron the same chemical determinations were made on these as on the surface soil samples.

In 1948 the plots that had received limestone at the rate of 3,000 pounds per acre had an average pH value of 5.92 as against 4.92 for the check plots in the surface six inches. Corresponding values for per cent base saturation were 66.6 and 28.5. Apparently the base exchange capacity of the samples, which in general approximated 9.5 milliequivalents per 100 grams of soil, was not affected by the limestone treatments.

In the case of the seven surface samples collected in 1930 the average values for total nitrogen and exchangeable potassium were 0.22 per cent and 0.16 milliequivalents respectively. The corresponding values for comparable samples taken in 1948 were 0.19 per cent and 0.29 milliequivalents. The results of analyses also indicated a decrease in exchangeable magnesium during the 18 year period. These changes were rather consistent although the plots involved received different limestone treatments.

The water-soluble boron content of the 1930 samples ranged from 0.38 to 0.49 parts per million. By 1948 a rather consistent decrease of approximately 30 per cent had occurred. This decrease did not appear to be related to the amounts of limestone applied and may be attributed to loss by leaching and removal by crops.

The 1948 samples showed that there were no significant differences in the boron content of soils which had received different amounts of limestone. There was, however, a significant difference in the boron content of limed and unlimed soils.

The limestone applications had little effect on the reaction of the subsoils. While exchangeable magnesium decreased during the 21 year period, exchangeable potassium remained rather constant.

Yield data, as recorded from 1940 to 1948 inclusive, were treated statistically. The limestone treatments had no effect on potato yields but resulted in significant increases in the yields of the other two crops in the rotation. The average yield of potatoes on unlimed plots was 191 bushels per acre as compared to 190 bushels per acre from plots which had received the highest rate of limestone application. Barley yields under similar conditions were 28.2 and 35.5 bushels per acre respectively. In the case of clover unlimed plots yielded 0.873 tons per acre as against 1.611 tons where limestone was used at the rate of 3,000 pounds per acre.

In recent years the incidence of potato scab has tended to increase on those plots receiving the higher rates of limestone.

The effect of limestone on boron availability, as determined by soil and plant analyses, was investigated in a greenhouse experiment.

Ladino clover, grown on soil containing 0.36 parts per million of water-soluble boron, had a boron content of 36.4 parts per million. The pH value of the soil was 5.0. When the soil was limed to a pH of 6.0 its water-soluble boron content was reduced approximately one-third and the boron content of the clover to 0.33 parts per million.

A second crop of clover, grown on the same soil after it was limed to a pH of 6.47, contained 12.8 parts per million of boron. The water-soluble boron content of the soil at that pH was 0.15 parts per million.

The correlation between the water-soluble boron in the soil and the boron content of the ladino clover was significant.

In the first clover crop calcium-boron ratios ranged from 566 to 1 to 723 to 1. In the second crop the largest ratio was 2078 to 1. No visual symptoms of boron deficiency were observed in either crop.

The effect of calcium carbonate, gypsum, magnesium carbonate, manure, alfalfa and sodium hydroxide, on the water-soluble boron content of soil, was studied in a laboratory experiment.

Calcium carbonate, applied at 0, 1, 2, 4, 6 and 8 tons per acre, resulted in a range of pH values from 4.70 to 7.38.

The untreated soil contained 0.32 parts per million of water-soluble boron as compared with 0.13 parts per million where 8 tons of calcium carbonate was applied. A highly significant negative correlation existed between the amounts of calcium applied and the water-soluble boron content of the treated soils.

Reductions in water-soluble soil boron resulting from applications of gypsum were negligible. The amounts of calcium added were the same as where calcium carbonate was applied. Soil acidity was slightly increased by the gypsum treatments. The correlation between the amounts of calcium added and the water-soluble boron content of the treated samples was not significant.

Decreases in water-soluble soil boron, obtained by applying magnesium carbonate, were almost identical with those resulting from the use of calcium carbonate. The range in pH values was similar. The negative correlation between the amounts of magnesium applied and the water-soluble boron content of the treated soils was highly significant.

Applications of manure or of alfalfa, at rates of 10, 20, 40, 60 and 100 tons per acre, increased the water-soluble boron content of the soil. The increases, ranging from 3.1 to 40.6 per cent with manure and from 12.9 to 154.8 per cent with alfalfa, varied directly with the rates of application.

Decreasing amounts of water-soluble boron were found in soils treated with increasing rates of manure and calcium carbonate. This was also true when alfalfa was used in place of manure. All combinations of manure and calcium carbonate resulted in lower values for water-soluble soil boron than occurred in the check soil. Where alfalfa and calcium carbonate mixtures were applied, no combination reduced the water-soluble soil boron content to the level found in the check soil.

When expressed as parts per million of water-soluble boron the reductions that occurred with calcium carbonate, whether applied alone or in combination with manure or alfalfa, tended to be the same for any one rate of application irrespective of the amount of water-soluble boron present.

Increasing amounts of sodium hydroxide were used to obtain a range of soil pH values from 4.82 to 9.72. The increasing pH values were accompanied by a reduction and then an increase in water-soluble boron. The greatest decrease amounted to 31.3 per cent and occurred at pH values of 7.50 and 7.75. At a pH value of 9.72 the soil contained 15.6 per cent more water-soluble boron than was found in the check soil. The correlation between pH value and content of water-soluble boron was not significant.

The addition of increasing amounts of calcium carbonate to a soil previously treated with sodium hydroxide resulted in decreased contents of water-soluble boron. On a percentage basis the decreases, which showed some inconsistencies in respect to the amounts of calcium carbonate applied, were less than those that occurred where the soil had not been previously treated with sodium hydroxide. The pH values of soils receiving both sodium hydroxide and calcium carbonate ranged from 8.23 to 9.20. There was a significant negative correlation between these pH values and the water-soluble boron in the soil. The negative correlation between the amounts of calcium applied and the water-soluble boron in the soils was not significant.

BIBLIOGRAPHY

Ahlgren, Gilbert H. (1949)
Forage Crops, ed. 1. McGraw-Hill Book Company, Inc., New York. 418 pp.

Albrecht, Wm. A. (1946)
Plant nutrition and the hydrogen ion. V. Relative effectiveness of coarsely ground and finely pulverized limestone. Soil Sci. 61: 265-271.

____ and R. A. Schroeder. (1941)
Plant nutrition and the hydrogen ion. I. Plant nutrients used more effectively in the presence of hydrogen ions. Soil Sci. Soc. Amer. Proc. 6: 195-196.

Arron, D. I., and C. M. Johnson. (1942)
Influence of hydrogen ion concentration on the growth of higher plants under controlled conditions. Plant Physiol. 17: 525-539.

Aslander, Alfred. (1952)
Standard fertilization and liming as factors in maintaining soil productivity. Soil Sci. 74: 181-195.

Association of Official Agricultural Chemists (1945)
Official and Tentative Methods of Analysis, ed. 6. Washington, D.C.

____ (1950)
Official Methods of Analysis, ed. 7. Washington, D.C.

Bear, F. E., and S. J. Toth. (1948)
Influence of calcium on the availability of other soil cations. Soil Sci. 65: 69-74.

Beeson, K. C. (1945)
The occurrence of mineral nutritional diseases of plants and animals in the United States. Soil Sci. 60: 9-13.

Berger, K. C. (1948)
Soil fertility investigations with potatoes in Wisconsin. Amer. Potato Jour. 25: 377-386.

____ (1949)
Boron in soils and crops. Norman, A. G., Editor. Advances in Agronomy, Vol. 1. Academic Press Inc., New York, 1949. 439 pp.

____ and E. Truog. (1940)
Boron deficiencies as revealed by plant and soil tests. Jour. Amer. Soc. Agron. 32: 297-301.

____ and ____ (1945)
Boron availability in relation to soil reaction and organic matter content. Soil Sci. Soc. Amer. Proc. 10: 113-116.

Blair, A. W., and A. L. Prince. (1934)
The influence of lime on the reaction of subsoils. Jour. Agr. Res. 48: 469-473.

Boulet, L. J., and Lucien Choiniere. (1953)
Phosphate and potash effects on ladino clover swards. Better Crops with Plant Food 37: 6-14, cont., 39-46.

Bradfield, Richard. (1941)
Calcium in the soil. I Physico-chemical relations. Soil Sci. Soc. Amer. Proc. 6: 8-15.

Brenchley, W. E., and Katherine Warington. (1927)
The role of boron in the growth of plants. Ann. Bot. 41: 167-187.

Brown, B. A., and Allan King. (1939)
Soil conditions under which alfalfa responded to boron. Soil Sci. Soc. Amer. Proc. 4: 310-313.

____ and R. I. Munsell. (1938)
Soil acidity at various depths as influenced by time since application, placement and amount of limestone. Soil Sci. Soc. Amer. Proc. 3: 217-221.

Bryan, O. C. (1923)
Effect of reaction on growth, nodule formation, and calcium content of alfalfa, alsike clover and red clover. Soil Sci. 15: 23-35.

Colwell, W. E., and R. W. Cummings. (1944)
Chemical and biological studies on aqueous solutions of boric acid and of calcium, sodium and potassium metaborates. Soil Sci. 57: 37-49.

Carolus, R. L. (1944)
Influence of nitrogen, phosphorus, potassium and calcium on tuber and foliage weight of potatoes. Amer. Potato Jour. 21: 199-203.

Cook, R. L., and C. E. Millar. (1939)
Some soil factors affecting boron availability. Soil Sci. Soc. Amer. Proc. 4: 297-301.

____ and ____. (1949)
Plant nutrient deficiencies. Michigan Agricultural Experiment Station, East Lansing, Special Bull. 353, 80 pp.

Cook, H. T., and T. J. Nugent. (1939)
The influence of acid-forming and non-acid-forming fertilizer on the development of potato scab. Amer. Potato Jour. 16: 1-5.

Cooper, H. P. (1947)
Minor plant nutrients. Commercial Fertilizer 74: 14-19, cont., 42-44.

____ W. R. Paden, W. H. Garman, and N. R. Page. (1948)
Properties that influence availability of calcium in the soil to plants. Soi Sci. 65: 75-96.

Cowan, P. R. (1952)
The development of barley varieties in Canada. Agricultural Institute Review 7: 23-24.

Davis, Franklin L. (1949)
Effects of liming on response to minor elements of crimson clover, soybeans and alyce clover. Agron. Jour. 41: 368-374.

Drake, M., D. H. Sieling, and G. D. Scarseth. (1941)
Calcium-boron ratio as an important factor in controlling the boron starvation of plants. Jour. Amer. Soc. Agron. 33: 454-462.

Dregne, H. E., and W. L. Powers. (1942)
Boron fertilization of alfalfa and other legumes in Oregon. Jour. Amer. Soc. Agron. 34: 902-912.

Dunklee, D. E., and A. R. Midgley. (1944)
The need for borax on fourteen crops. Better Crops with Plant Food 28: 15-19, cont., 43-49.

Eaton, F. M. (1944)
Deficiency, toxicity, and accumulation of boron in plants. Jour. Agr. Res. 69: 237-277.

____ and L. V. Wilcox. (1939)
The behavior of boron in soils. United States Department of Agriculture, Washington, Tech. Bull. 696. 58 pp.

Fippin, Elmer O. (1939)
Soil acidity and liming and some factors that should determine the standards for lime for the soil. Symposium on Lime. Columbus Regional Meeting. American Society for Testing Materials.

Giddens, Joel, and Stephen J. Toth. (1951)
Growth and nutrient uptake of ladino clover grown on red and yellow and grey-brown podzolic soils containing varying ratios of cations. Agron. Jour. 43: 209-214.

Hanna, W. J., and E. R. Purvis. (1941)
Effect of borax and lime on activity of soil microorganisms in Norfolk fine sandy loam. Soil Sci. 52: 275-281.

Harris, H. C. (1937)
Effect of lime on the availability and fixation of potash in soils. Soil Sci. 44: 265-275.

Hawkins, A., J. A. Chucka and B. E. Brown. (1941)
Minor element studies on potatoes in Maine. Amer. Potato Jour. 19: 234-239.

Jenny, H., and E. R. Slade. (1934)
The potassium lime problem in soils. Jour. Amer. Soc. Agron. 26: 162-170.

Jones, H. E., and G. D. Scarseth. (1944)
The Ca-B balance in plants as related to boron needs. Soil Sci. 57: 15-24.

Kelley, W. P. (1940)
The agronomic importance of calcium. Soil Sci. 40: 103-109.

Klages, K. H. W. (1949)
Ecological Crop Geography. The Macmillan Company, New York. 615 pp.

Kubota, J., K. C. Berger, and E. Truog. (1949)
Boron movement in soils. Soil Sci. Soc. Amer. Proc. 13: 130-134.

Lucas, R. E., and C. D. Scarseth. (1947)
Potassium, calcium and magnesium balance and reciprocal relationship in plants. Jour. Amer. Soc. Agron. 39: 887-897.

Lynd, J. Q., and L. M. Turk. (1948)
Overliming injury on an acid sandy soil. Jour. Amer. Soc. Agron. 40: 205-215.

MacIntire, W. H., and B. W. Hatcher. (1942)
Evidence in support of a new concept as to the end product of superphosphate in limed soils. Soil Sci. 53: 43-54.

Marsh, R. P. (1942)
Comparative study of the calcium-boron metabolism of representative dicots and monocots. Soil Sci. 53: 75-78.

____ and J. W. Shive. (1941)
Boron as a factor in the calcium metabolism of the corn plant. Soil Sci. 51: 141-151.

Marshall, C. E. (1948)
Ionization of calcium from soil colloids and its bearing on soil-plant relationships. Soil Sci. 65: 57-69.

McCall, A. G. (1923)
The influence of acidity itself on plant growth without regard to other factors. Jour. Amer. Soc. Agron. 15: 290-297.

McMurtrey, J. E. Jr. (1929)
The effect of boron deficiency on the growth of tobacco plants in aerated and unaerated solutions. Jour. Agr. Res. 38: 371-380.

____ (1948)
Chap. VIII. Visual symptoms of malnutrition in plants. Hermine B. Kitchen, Editor. Diagnostic Techniques for Soils and Crops, The American Potash Institute, Washington, D.C. 308 pp.

Midgley, A. R., and D. E. Dunklee. (1939)
The effect of lime on the fixation of borates in soils. Soil Sci. Soc. Amer. Proc. 4: 302-307.

Moschler, W. W., S. S. Obenshain, R. P. Cocke and H. M. Camper. (1949)
The effect of varying amounts of ground limestone on the pH and base exchange properties of Sassafras fine sandy loam. Soil Sci. Soc. Amer. Proc. 14: 123-125.

Moser, F. (1943)
Calcium nutrition at respective pH levels. Soil Sci. Soc. Amer. Proc. 7: 339-344.

Muhr, G. R. (1940)
Available boron as affected by soil treatments. Soil Sci. Soc. Amer. Proc. 5: 220-226.

Munsell, R. I., and B. A. Brown. (1943)
The boron content of certain forage and vegetable crops. Jour. Amer. Soc. Agron. 35: 401-408.

Naftel, J. A. (1937a)
Soil liming investigations. III. The influence of calcium and a mixture of calcium and magnesium carbonates on certain chemical changes in soils. Jour. Amer. Soc. Agron. 29: 526-536.

____ (1937b)
The influence of excessive liming on boron deficiency in soils. Soil Sci. Soc. Amer. Proc. 2: 383-384.

____ (1939)
Colorimetric microdetermination of boron. Ind. and Eng. Chem., Anal. Ed. 11: 407-408.

Nelson, W. L., and N. C. Brady. (1943)
Effect of subsurface application of lime on yield, scab, and nutrient uptake of Irish potatoes. Soil Sci. Soc. Amer. Proc. 8: 313-316.

Olson, R. V., and K. C. Berger. (1946)
Boron fixation as influenced by pH, organic matter content and other factors. Soil Sci. Soc. Amer. Proc. 11: 216-220.

Parks, R. Q. (1944)
The fixation of added boron by Dunkirk fine sandy loam. Soil Sci. 57: 405-416.

____ and B. T. Shaw. (1941)
Possible mechanisms of boron fixation in soil. I. Chemical. Soil Sci. Soc. Amer. Proc. 6: 219-223.

Parks, W. L., and J. L. White. (1952)
Boron retention by clay and humus systems saturated with various cations. Soil Sci. Soc. Amer. Proc. 16: 298-300.

Peech, M. (1941)
Availability of ions in light sandy soils as affected by soil reaction. Soil Sci. 51: 473-486.

____ and Richard Bredfield. (1943)
The effect of lime and magnesia on the soil potassium and on the absorption of potassium by plants. Soil Sci. 55: 37-48.

____ L. T. Alexander, L. A. Dean and J. F. Reed. (1947)
Methods of soil analysis for soil-fertility investigations. United States Department of Agriculture, Washington, Circ. No. 757.

Pierre, W. H., and C. A. Bower. (1943)
Potassium adsorption by plants as affected by cationic relationships. Soil Sci. 55: 23-36.

____ and G. M. Browning. (1935)
The temporary injurious effect of excessive liming of acid soils and its relation to phosphate nutrition of plants. Jour. Amer. Soc. Agron. 27: 742-759.

Piland, J. R., C. F. Ireland, and H. M. Reisenauer. (1944)
The importance of borax in legume seed production in the south. Soil Sci. 57: 75-84.

Powers, W. L., and J. V. Jordon. (1950)
Boron in Oregon soils and plant nutrition. Soil Sci. 70: 99-107.

Purvis, E. R. (1939)
The present status of boron in American agriculture. Soil Sci. Soc. Amer. Proc. 4: 316-321.

____ and O. W. Davidson. (1948)
Review of the relation of calcium to availability and absorption of certain trace elements by plants. Soil Sci. 65: 111-116.

Reed, J. Fielding and R. W. Cummings. (1948)
Use of soluble sources of calcium in plant growth. Soil Sci. 65: 103-111.

Rogers, H. T. (1947)
Water-soluble boron in coarse textured soils in relation to need of boron fertilization for legumes. Jour. Amer. Soc. Agron. 39: 914-928.

Salter, R. M., and C. J. Schollenberger. (1930)
Criteria for the evaluation of agricultural ground limestone. Symposium on Lime. Columbus Regional Meeting. American Society for Testing Materials.

Schaller, Frank W. (1948)
Boron content and requirements of West Virginia soils. Soil Sci. 66: 335-346.

Scripture, P. N., and J. S. McHargue. (1943)
Effect of boron deficiency on the soluble nitrogen and carbohydrate content of alfalfa. Jour. Amer. Soc. Agron. 35: 988-992.

Shuh, J. E. (1952)
Barley production and utilization in the Maritimes. Agricultural Institute Review 7: 18.

Smith, H. V. (1949)
Boron as a factor in Arizona's agriculture. Arizona Agricultural Experiment Station, Tuscon, Tech. Bull. 118, 44 pp.

Snider, H. J. (1946)
Soil requirements for red clover. Better Crops with Plant Food 30: 17-19, cont., 41.

Sommer, A. L., and C. B. Lipman. (1926)
Evidence of the indispensable nature of boron for higher green plants. Plant Physiol. 1: 231-249.

Stewart, Ivan and F. E. Bear. (1951)
Ladino clover - Its mineral requirements and chemical composition. New Jersey Agricultural Experiment Station, New Brunswick, Bull. 759, 32 pp.

Stinson, C. H. (1953)
Relation of water-soluble boron in Illinois soils to boron content of alfalfa. Soil Sci. 75: 31-36.

Truninger, E. (1944)
Experiments and studies on the effects of boron as a trace element. Rev. Applied Mycol. 23: 277-278.

Truog, E. (1918)
Soil acidity. I. Its relation to the growth of plants. Soil Sci. 5: 169-195.

____ (1947)
The liming of soils. The Yearbook of Agriculture 1943-1947. United States Department of Agriculture, Washington, D.C. 944 pp.

____ (1948)
Lime in relation to availability of plant nutrients. Soil Sci. 65: 1-9.

Tulin, A. S. (1940)
Significance of boron for the utilization of the mineral nutritional elements of podzol soils. Pedology (U.S.S.R.) 3: 39-53. Seen in abstract only. Soils and Fertilizers 4: 31, 1941.

Warington, Katherine. (1923)
The effect of boric acid and borax on the broad bean and certain other plants. Ann. Bot. 37: 629-672.

____ (1934)
Studies in the absorption of calcium from nutrient solutions with special reference to the presence or absence of boron. Ann. Bot. 48: 743-776.

Webber, L. R., F. F. Morwick, T. J. Heeg, N. J. Thomas and N. R. Richards. (1952)
Ontario soils - their use, management and improvement. Ontario Department of Agriculture, Toronto, Bull. 492, 44 pp.

Whetstone, R. R., Wm. O. Robinson, and H. C. Byers. (1942)
Boron distribution in soils and related data. United States Department of Agriculture, Washington, Tech. Bull. 797, 32 pp.

Whiteside, G. B. (1950)
Soil Survey of Prince Edward Island. Experimental Farms Service, Canada Department of Agriculture, Ottawa. 83 pp.

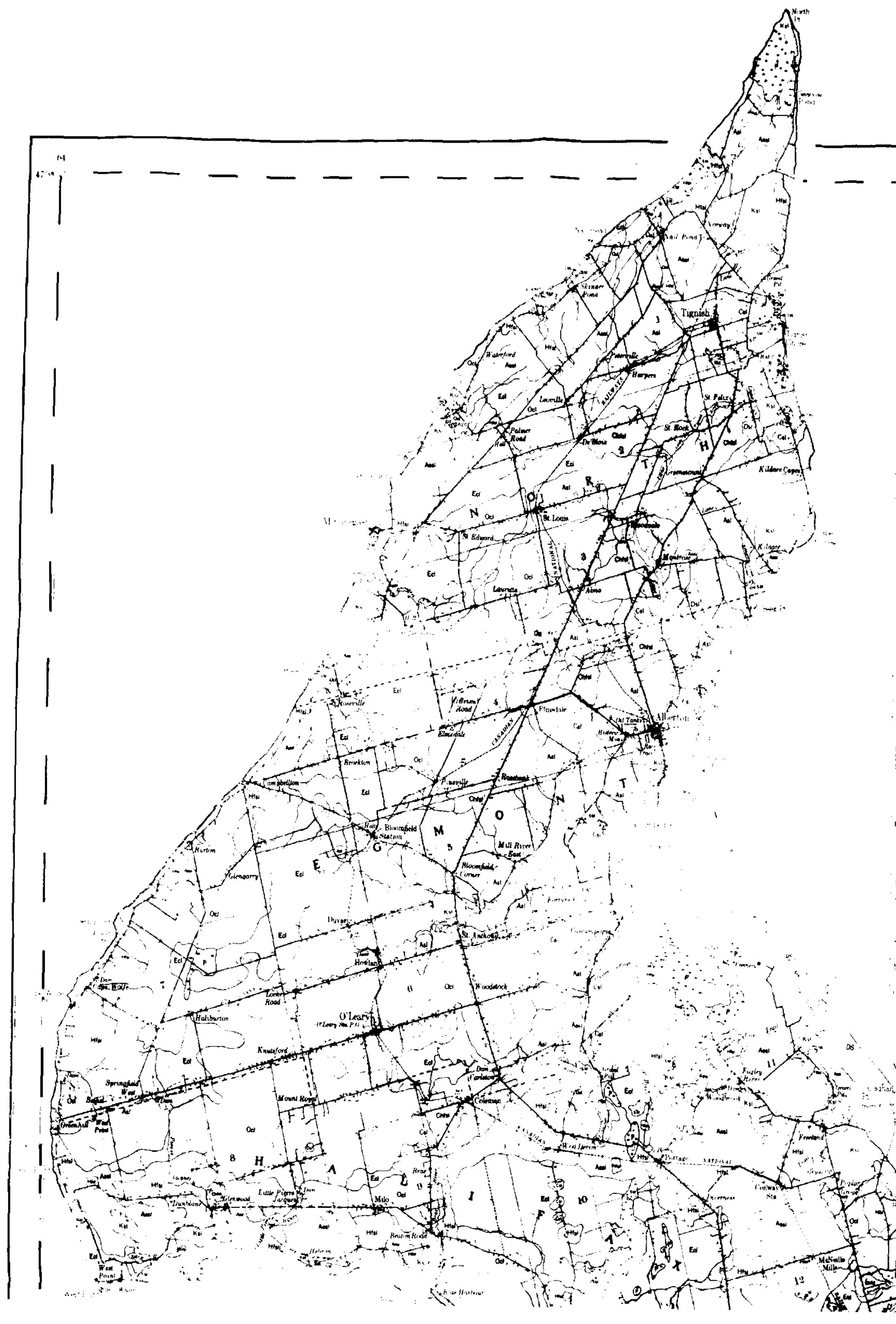
Wilson, Harold K. (1948)
Grain Crops, ed. I, McGraw-Hill Book Company, Inc., New York. 384 pp.

Wilson, C. M., R. L. Lovvorn and W. W. Woodhouse, Jr. (1951)
Movement and accumulation of water-soluble boron within the soil profile. Agron. Jour. 43: 363-367.

Woodbridge, C. G. (1950)
Boron in Canadian agriculture. Canadian Chemistry and Process Industries 34: 403-404, cont., 406-408.

Wolf, Benjamin. (1940)
Factors influencing availability of boron in soil and its distribution in plants. Soil Sci. 50: 209-216.

York, E. T., and H. T. Rogers. (1947)
Influence of lime on the solubility of potassium in soils and on its availability to plants. Soil Sci. 63: 467-477.



LEGEND

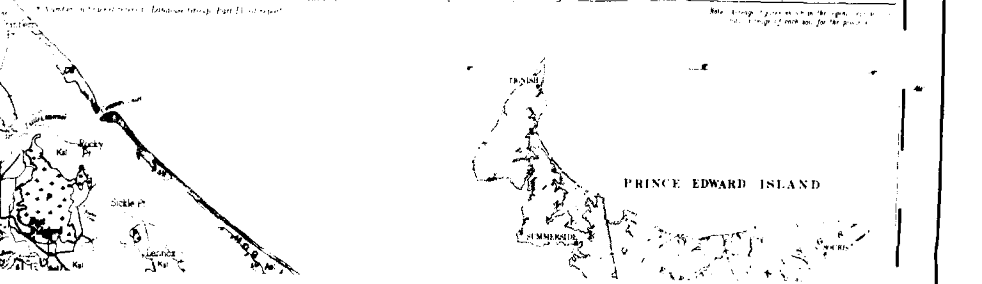
ZONE: Podzol. Leached strongly acid soils

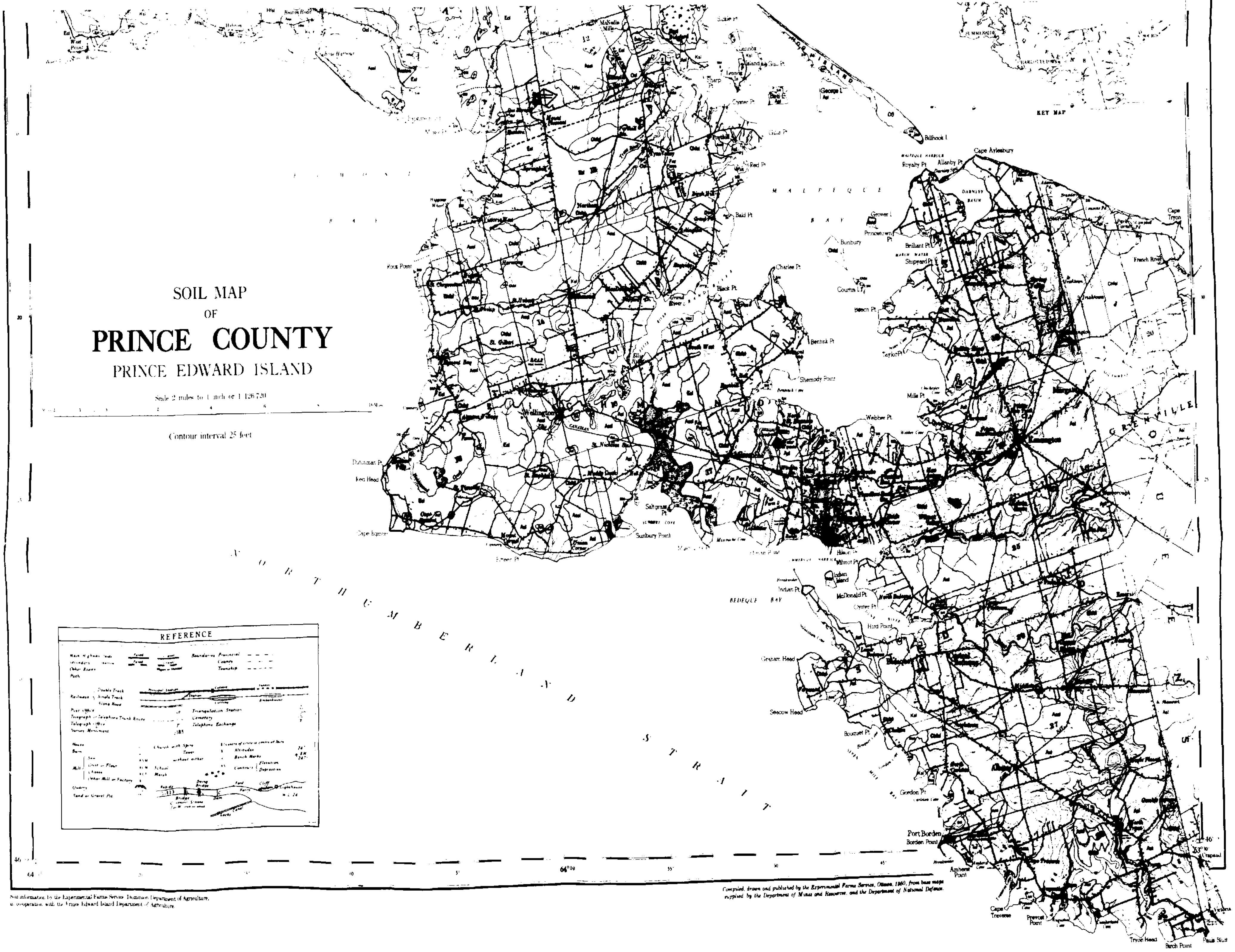
SOIL SERIES AND NAME	Alberry fine sandy loam	Charlottetown fine sandy loam	Culloden sandy loam	Haliburton fine sandy loam	Pownal fine sandy loam	Dunstaffnage sandy loam	Kildare sandy loam
MAP COLOUR AND SYMBOL	Afsl	Chfsl	Csl	Hfsl	Pfsl	Dsl	Ksl
ACREAGE	318,900	496,000	192,980	27,340	4,900	33,960	18,210
PER CENT OF TOTAL AREA	23.1	35.6	14.0	2.0	0.3	2.5	[illegible]
DESCRIPTION OF SURFACE SOIL AND SUBSOIL	Light brown to brown fine sandy loam, over weak brownish-red sandy loam to fine sandy loam. Friable to very friable	Light brown to brown fine sandy loam to very fine sandy loam, over weak brownish-red fine sandy loam to very fine sandy loam. Friable to firm	*Greyish brown to light brown* sandy loam to light fine sandy loam, over weak brownish-red sandy loam. Very friable porous. Variable gravel	Brown to dark brown fine sandy loam over dusky reddish-brown fine sandy loam. Friable	Brown to dark brown fine sandy loam to loam, over dark red very fine sandy loam, with lenses of clay	Greyish to light brown sandy loam to light fine sandy loam, over light brown sandy loam. Loose gravelly and porous	Grey, dark grey and grey-brown loamy fine sand to light fine sandy loam over brown to reddish-brown sandy loam. Loose porous
PARENT MATERIAL	Brownish-red sandy loam to fine sandy clay loam derived mainly from brown and red sandstone material	Red fine sandy loam to fine sandy clay loam, derived from red sandstone, shale and conglomerate	Brownish-red sandy loam gravelly to stony derived mainly from brown and red sandstone material	Dusky reddish-brown fine sandy loam derived largely from soft dusky-red sandy material highly micaceous	Similar to Charlottetown series, some modification by water action	Light brown gravelly to stony water-worked sandstone and conglomerate material	[illegible]
TOPOGRAPHY	Undulating to gently rolling			Undulating		Undulating to gently rolling (Kames and Eskers)	[illegible]
NATURAL DRAINAGE	Well-drained, surface run-off medium to high, subsoil drainage moderate		Rapid to excessive surface run-off medium to high, subsoil drainage rapid	Well drained, surface run-off moderate to high. Subsoil drainage moderate to rapid	Moderately well drained, surface run-off medium, subsoil drainage moderate, tends to be slow in places	Excessive. Surface run-off medium to high. Subsoil drainage very rapid	[illegible]
SOIL REACTION OR ACIDITY	Strongly acid			Moderately acid	Variable	Strongly acid	[illegible]
LAND-USE GROUP	Good agricultural land generally (1)*, but 11.2 per cent consists of marginal (4) to non-agricultural land (6) because of nature of topography and susceptibility to erosion		Fair to marginal (3) agricultural land generally, with 7.9 per cent non-agricultural land (6)	Fair to good agricultural land (2)		Sub-marginal land (5)	[illegible]
CROP ADAPTIBILITY AND UTILIZATION	Suitable to wide range of crops. Largely under cultivation; mixed farming, dairying and potatoes. Main crops clover and timothy hay, oats, barley, turnips and potatoes		Restricted crop adaptability, marginal to poor grassland soil. *Large proportion under* forest or blueberry barrens. Mixed farming, dairying and potatoes. Main crops timothy hay and clover hay, field roots and potatoes	Crop adaptability and utilization similar to Charlottetown series *but not quite as* good a grassland soil. Soil moisture conditions limiting factor	Well suited to hay, pasture and grain. Practically all *under* cultivation. Mixed farming and dairying	[illegible]	Narrow crop adaptability range. Fair potato soil, poor grass and soil. Considerable acreage cleared. Mixed farming and potatoes
MAIN SOIL PROBLEMS	Soil fertility and erosion		Soil fertility, erosion and [illegible]	Soil fertility and low moisture [illegible]	[illegible] and drainage	Soil fertility, low moisture-holding capacity	

SOIL SERIES AND NAME	Armedale sandy loam	O'Leary clay	Egmont clay loam	Queens clay loam	Peat	Salt Marsh	Dune sand
MAP COLOUR AND SYMBOL	Asal	Ocl	Ecl	Qcl	P	SM	DS
ACREAGE	141,760	62,655	59,180	3,200	9,790	2,775	7,050
PER CENT OF TOTAL AREA	10.1	4.6	4.4	0.2	0.7	0.2	0.5
DESCRIPTION OF SURFACE SOIL AND SUBSOIL	Brown to dark brown or black fine sandy loam to clay loam, over dull brown or brownish-red sandy loam to sandy clay loam. Very firm	Greyish-brown to dark brown fine sandy loam to clay loam, over weak reddish-brown clay loam. Firm. Permeable	Dark grey to black clay loam over deep reddish-brown clay loam. Very firm. Slowly permeable	Brownish-grey to dark brown loam to clay loam, over dusky red clay loam. Firm. Permeable	Brown to dark brown or black fibrous (mossy or woody) organic material several feet thick over sandy loam to clay	Brown to reddish-brown fine sandy loam, silty loam and silty clay, over brownish or grey clay loam. Little or no profile differentiation. Derived from a wastage of uplands and from tidal deposits	Grey to pale yellow sand to loamy sand. No profile development. 25 feet or more in depth
PARENT MATERIAL	Sandy loam to sandy clay [illegible] similar to associated better drained soils. Firm. Nearly imper[vious]	Reddish brown to dark or dusky red clay loam, derived largely from sandstone materials with some igneous material. Firm. Permeable	Very firm to compact. Almost impervious	Purplish-red clay loam to clay derived largely from *Carboniferous sandstone* material			
TOPOGRAPHY	Very gently undulating to level		Gently undulating		Nearly level to depressional		Undulating to gently rolling
NATURAL DRAINAGE	Poor, surface run-off very low, may be ponded. Internal drainage very slow	Moderate to well drained, *surface run-off medium to* low. Internal drainage moderate	Imperfect to poor. Surface *run-off low to very low.* Internal drainage very low	Moderately well drained. *Medium to low surface run*-off, moderate subsoil drainage	Very poor	Poor to very poor. Fluctuates with tidal action	Excessive
SOIL REACTION OR ACIDITY	Variable		Moderately to strongly acid		Usually strongly acid	Variable	Slightly acid
LAND-USE GROUP	Sub-marginal agricultural land (5)	Good agricultural land (1)	Marginal agricultural land (4)	Fair to good agricultural land (2)	Non-agricultural land (6)		
CROP ADAPTIBILITY AND UTILIZATION	Practically all under forest [illegible]	Well suited to hay, grain, field roots and grassland. Not as well suited to potatoes as lighter textured soils. Large proportion under cultivation. Mixed farming, dairying and potatoes	Practically all under forest. Potential hay, grain, and pasture soil	Well suited to hay, grain, grassland and field roots. Mixed farming and dairying	Under natural vegetation	Unsuited to agricultural use, although some marsh hay occasionally cut on the better drained areas. Under natural vegetation	Non-agricultural soil. Sparsely covered with natural vegetation
MAIN SOIL PROBLEMS	Drainage	Soil fertility	Soil fertility and drainage	Soil fertility, drainage and erosion	Drainage		Drifting. Low moisture-holding capacity

* Number in brackets refers to Land-use Group, Part II of report

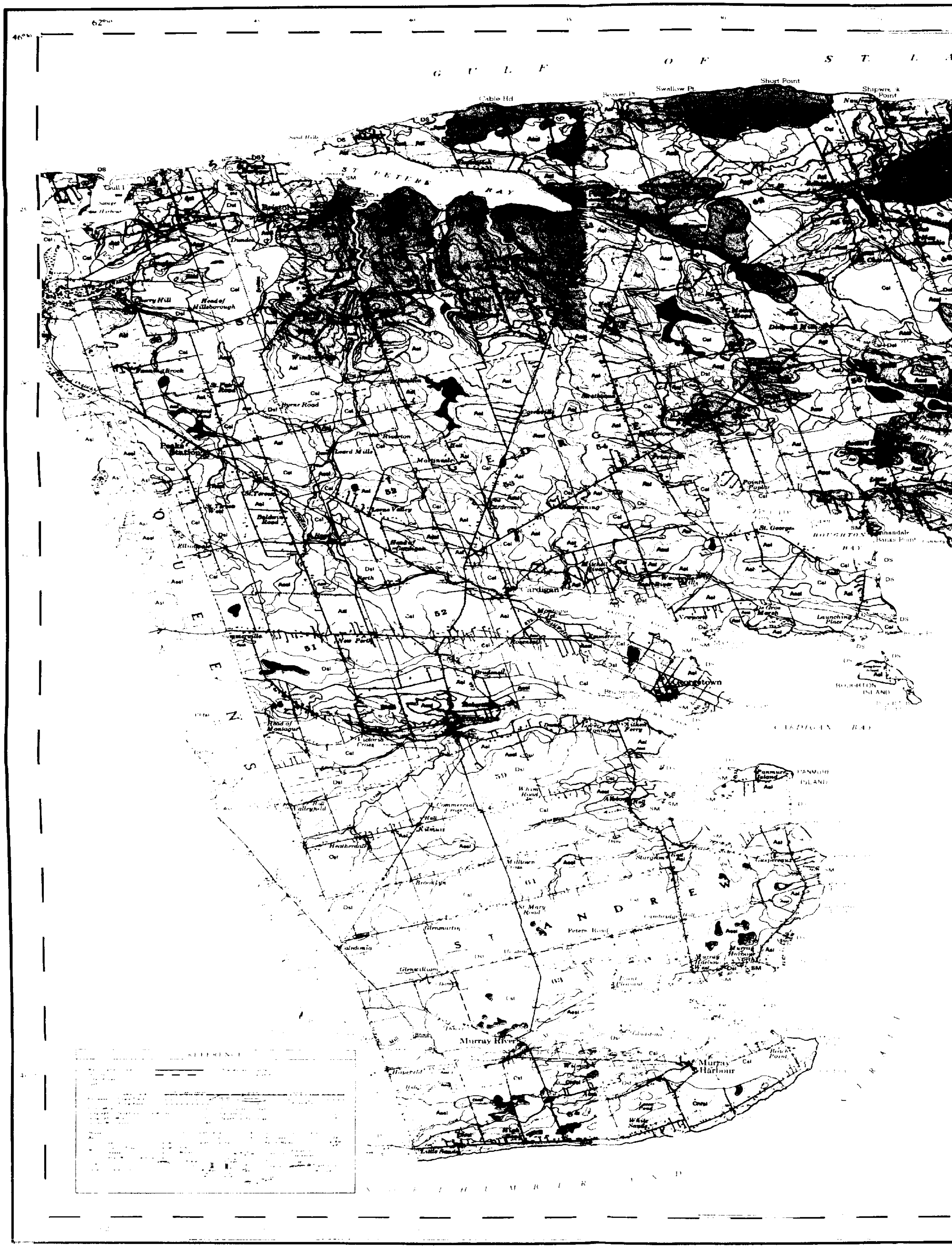
Note: Acreage figures [illegible] total acreage of each soil for the province



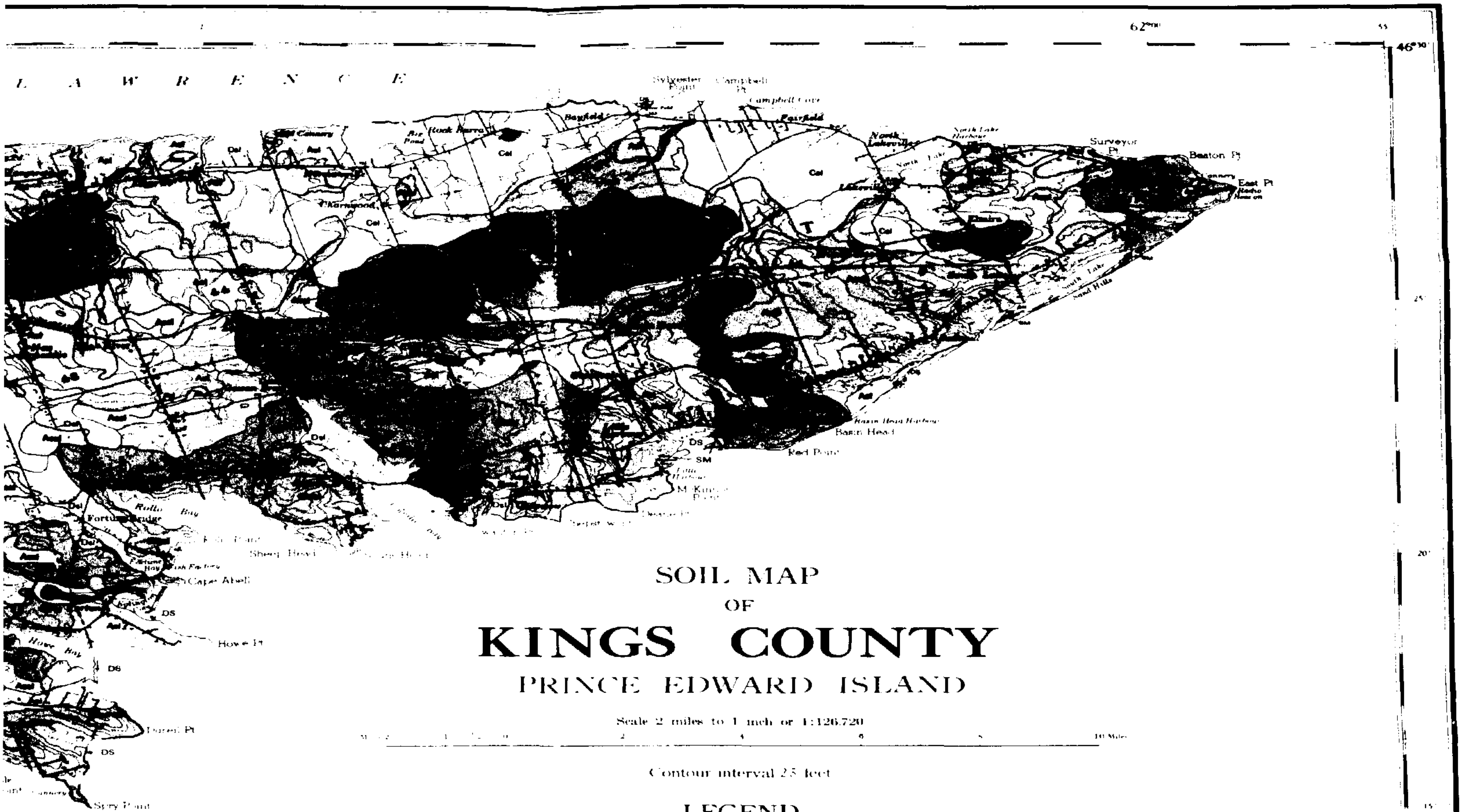


Soil information by the Experimental Farms Service, Dominion Department of Agriculture, in co-operation with the Prince Edward Island Department of Agriculture.

Compiled, drawn and published by the Experimental Farms Service, Ottawa, 1960, from base maps supplied by the Department of Mines and Resources, and the Department of National Defence.



62°
46°
G U L F O F S T. L
Cable Hd
Beaver Pt
Swallow Pt
Short Point
Shipwreck Point
Sand Hills
ST PETERS BAY
Head of Hillsborough
Peakes Station
Cardigan
Georgetown
St. Georges
Annandale
Banks Point
BOUGHTON ISLAND
CARDIGAN BAY
Panmure Island
PANMURE ISLAND
Head of Montague
Murray River
Murray Harbour
Brooklyn
Heatherdale
Kilmuir
Peters Road
Little Sands
Q U E E N S
S T A N D R E W
52
51
53
59
61
63



SOIL MAP OF KINGS COUNTY
PRINCE EDWARD ISLAND

Scale 2 miles to 1 inch or 1:126,720

Contour interval 25 feet

LEGEND

ZONE Podsol. Leached strongly acid soils

SOIL SERIES AND NAME	Alberry fine sandy loam	Charlottetown fine sandy loam	Culloden sandy loam	Haliburton fine sandy loam	Pownal fine sandy loam	Dunstaffnage sandy loam	Kildare sandy loam
MAP COLOUR AND SYMBOL	Aal	Chfsl	Csl	Hfsl	Pnsl	Dsl	Ksl
ACREAGE	318,900	486,000	192,900	27,340	4,900	33,880	18,210
PER CENT OF TOTAL AREA	23.3	35.6	14.0	2.0	0.3	2.5	1.3
DESCRIPTION OF SURFACE SOIL AND SUBSOIL	Light brown to brown fine sandy loam over weak brownish red sandy loam to fine sandy loam. Friable to very friable	Light brown to brown fine sandy loam to very fine sandy loam over weak brownish red fine sandy loam to very fine sandy loam. Friable to firm	Greyish brown to light brown sandy loam to light fine sandy loam over weak brownish red sandy loam. Very friable porous. Variable gravel	Brown to dark brown fine sandy loam over dusky reddish brown fine sandy loam. Friable	Brown to dark brown fine sandy loam to loam, over dark red very fine sandy loam, with lenses of clay	Greyish to light brown sandy loam to light fine sandy loam, over light brown sandy loam. Loose, gravelly and porous	Grey, dark grey and grey-brown loamy fine sand to light fine sandy loam, over brown to reddish-brown sandy loam. Loose, porous.
PARENT MATERIAL	Brownish red sandy loam to fine sandy clay loam derived from brownish red sandstone material	Red fine sandy loam to fine sandy clay loam derived from red sandstone, shale and conglomerate	Brownish red sandy loam gravelly to stony derived mainly from brown and red sandstone material	Dusky reddish brown fine sandy loam derived largely from soft dusky red sandy material highly micaceous	Similar to Charlottetown series, some modification by water action	Light brown gravelly to stony water-worked sandstone and conglomerate material	Weakly sorted sandy water-worked materials. Loose and porous. Bed-rock or till at 12 to 36 inches.
TOPOGRAPHY	Undulating to gently rolling			Undulating		Undulating to gently rolling (Kames and Eskers)	Gently undulating to nearly level
NATURAL DRAINAGE	Well drained, surface run-off medium to high, subsoil drainage moderate		Rapid to excessive, surface run-off medium to high, subsoil drainage rapid	Well drained, surface run-off moderate to high. Subsoil drainage moderate to rapid	Moderately well drained, surface run-off medium, subsoil drainage moderate, tends to be slow in places	Excessive. Surface run-off medium to high. Subsoil drainage very rapid	Well drained to excessive. Medium surface run-off and moderate to rapid subsoil drainage
SOIL REACTION OR ACIDITY	Strongly acid			Moderately acid	Variable	Strongly acid	Moderately to strongly acid
LAND-USE GROUP	Good agricultural land generally (1)*. For 11.2 per cent consists of marginal (3) to non-agricultural land (6) because of nature of topography and susceptibility to erosion		Fair to marginal (3) agricultural land generally with 7.0 per cent non-agricultural land (6)	Fair to good agricultural land (2)		Submarginal land (5)	Fair to marginal agricultural land (3)
CROP ADAPTIBILITY AND UTILIZATION	Suitable to wide range of crops. Largely under cultivation, mixed farming, dairying and potatoes. Main crops: clover and timothy hay, oats, barley, turnips and potatoes		Restricted crop adaptability, marginal to poor grassland soil. Large proportion under forest or blueberry barrens. Mixed farming, dairying and potatoes. Main crops: timothy hay and clover hay, field roots and potatoes	Crop adaptability and utilization similar to Charlottetown series, not quite as good a grassland soil. Soil moisture conditions limiting factor	Well suited to hay, pasture and grain. Practically all under cultivation. Mixed farming and dairying	Restricted crop adaptability, poor grassland. Largely under forest or blueberry barrens. Best suited to forest	Narrow crop adaptability range. Fair potato soil, poor grassland soil. Considerable acreage cleared. Mixed farming and potatoes
MAIN SOIL PROBLEMS	Soil fertility and erosion		Soil fertility, erosion and low moisture-holding capacity	Soil fertility and low moisture-holding capacity	Soil fertility and drainage	Soil fertility, low moisture holding capacity	

SOIL SERIES AND NAME	Armadale sandy loam	O'Leary clay	Egmont clay loam	Queens clay loam	Peat	Salt Marsh	Dune sand
MAP COLOUR AND SYMBOL	Aasl	Ocl	Ecl	Qcl	[illegible]	SM	DS
ACREAGE	141,760	62,165	59,180	3,200	9,790	2,775	7,020
PER CENT OF TOTAL AREA	10.4	4.6	4.4	0.2	0.7	0.2	0.5
DESCRIPTION OF SURFACE SOIL AND SUBSOIL	Brown to dark brown or black fine sandy loam to clay loam over dull brown or brownish red sandy loam to sandy clay loam. Very firm	Greyish brown to dark brown fine sandy loam to clay loam, over weak reddish brown clay. Very firm. Permeable	Dark grey to black clay loam over deep reddish brown clay loam. Very firm. Slowly permeable	Brownish grey to dark brown loam to clay loam over dusky red clay loam. Firm. Permeable	Brown to dark brown or black fibrous (mossy or woody) organic materials several feet thick, over sandy loam to clay	Brown to reddish brown fine sandy loam, silty loam and silty clay, over brownish or grey clay loam. Little or no profile differentiation. Derived from wastage of uplands and from tidal deposits	Grey to pale yellow sand to loamy sand. No profile development. 25 feet or more in depth
PARENT MATERIAL	Sandy loam to sandy clay loam or clay loam similar to associated better drained soils. Firm. Nearly impervious	Reddish brown to red or dusky red clay loam derived largely from sandstone materials with some igneous material. Firm. Permeable	Very firm to compact. Almost impervious	Purplish red clay loam to clay derived largely from Carboniferous sandstone material			
TOPOGRAPHY	Very gently undulating to level		Gently undulating		Nearly level to depressional		Undulating to gently rolling
NATURAL DRAINAGE	Poor, surface run-off very low, may be ponded. Internal drainage very slow	Moderate to well drained, surface run-off medium to low. Internal drainage moderate	Imperfect to poor. Surface run-off low to very low. Internal drainage very slow	Moderately well drained. Medium to low surface run-off, moderate subsoil drainage	Very poor	Poor to very poor. Fluctuates with tidal action	Excessive
SOIL REACTION OR ACIDITY	Variable	Moderately to strongly acid			Usually strongly acid	Variable	Slightly acid
LAND-USE GROUP	Submarginal agricultural land (5)	Good agricultural land (1)	Marginal agricultural land (3)	Fair to good agricultural land (2)	Non-agricultural land (6)		
CROP ADAPTIBILITY AND UTILIZATION	Practically all under forest cover	Well suited to hay, grain, field roots and grassland. Not as well suited to potatoes as lighter soils. Large proportion under cultivation. Mixed farming, dairying and potatoes	Practically all under forest. Potential hay, grain and pasture land	Well suited to hay, grain, grassland and field roots. Mixed farming and dairying	Under natural vegetation	Unsuited to agricultural use, although some marsh hay occasionally cut on the better drained areas. Under natural vegetation	Non-agricultural soil. Sparsely covered with natural vegetation
MAIN SOIL PROBLEMS	Drainage	Soil fertility	Soil fertility and drainage	Soil fertility, drainage and erosion	Drainage		Drifting. Low moisture-holding capacity

* Number in bracket refers to land use group, Part II of report

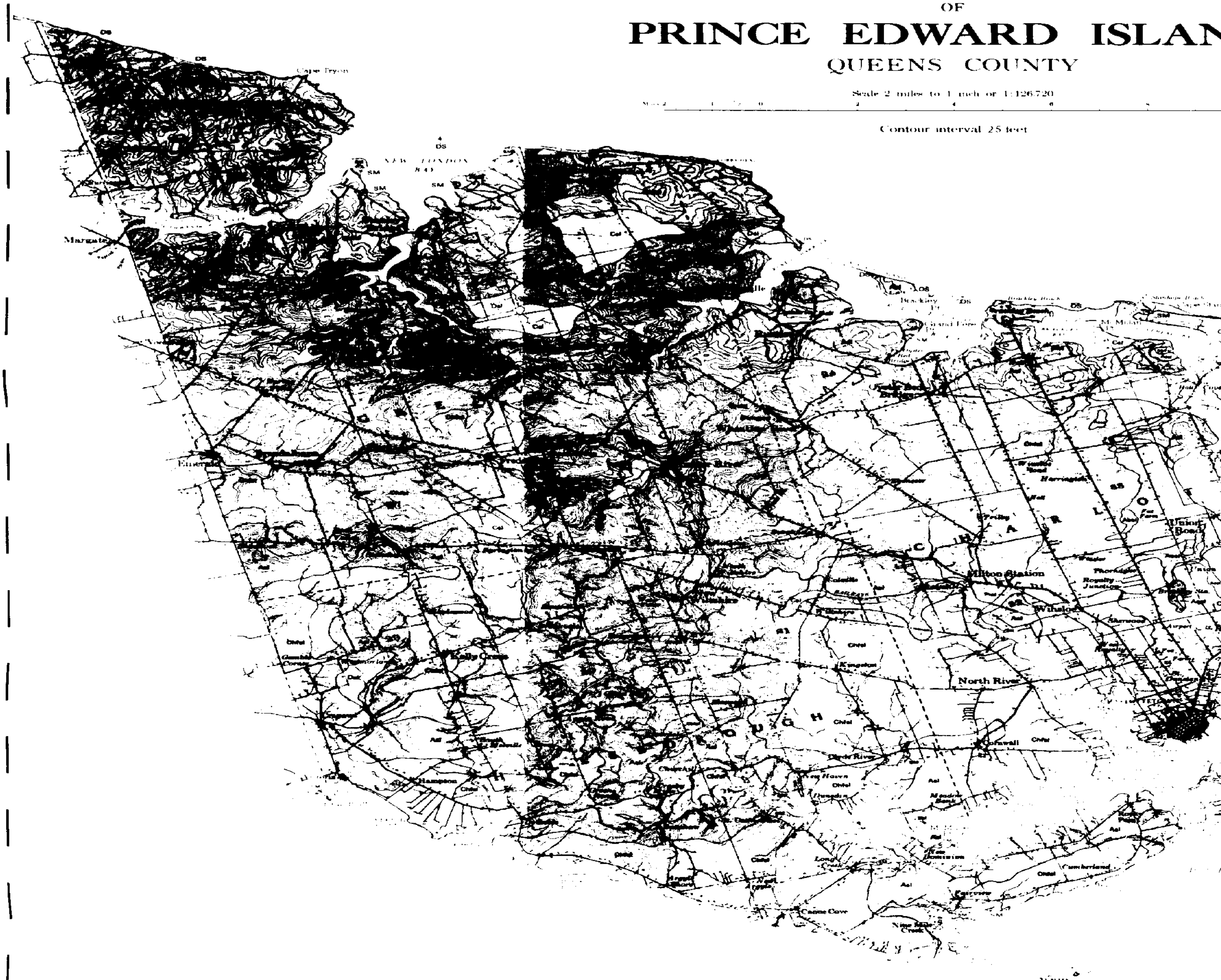
Note: Acreage figures shown in the legend represent the total acreage of each soil for the province

Compiled, drawn and published by the Experimental Farms Service, Ottawa, 1950, from base maps supplied by the Department of Mines and Resources and the Department of National Defence

SOIL MAP
OF
PRINCE EDWARD ISLAN
QUEENS COUNTY

Scale 2 miles to 1 inch or 1:126,720

Contour interval 25 feet



LEGEND

SOIL SERIES AND NAME	[illegible] sandy loam	O'Leary clay	Egmont clay loam	Queens clay loam	Peat	Salt Marsh	Dune sand
MAP COLOUR AND SYMBOL	Aasl	Ocl	Ecl	Qcl	P	SM	DS
ACREAGE	[illegible]	[illegible]	[illegible]	3,200	[illegible]	[illegible]	7,020
PER CENT OF TOTAL AREA	[illegible]	[illegible]	[illegible]	0.2	[illegible]	[illegible]	0.5
DESCRIPTION OF SURFACE SOIL AND SUBSOIL	Brown to dark brown [illegible]	Greyish brown to dark brown fine sandy loam [illegible]	Dark grey to black [illegible]	Brownish grey to dark brown loam to clay loam over dusky red clay loam. Firm. Permeable	Brown to dark brown or black fibrous mosses or woody organic materials several feet thick over sandy loam to clay	Brown to reddish brown fine sandy loam, silty loam and silty clay over brownish or grey clay loam. Little or no profile differentiation. Derived from wastage of uplands and from tidal deposits	Grey to pale yellow sand to coarse sand. No profile development. 25 feet or more in depth
PARENT MATERIAL	[illegible]	Reddish brown to dark or dusky red clay loam derived largely from sandstone materials [illegible]. Firm. Permeable	Very firm to compact [illegible]	Purplish red clay loam to clay derived largely from Carboniferous sandstone material			
TOPOGRAPHY	[illegible]		Gently undulating		Nearly level to depressional		Undulating to gently rolling
NATURAL DRAINAGE	[illegible]	Moderate to well drained [illegible]	Imperfect to poor [illegible]	Moderately well drained. Medium to low surface run-off, moderate subsoil drainage	Very poor	Poor to very poor. Fluctuates with tidal action	Excessive
SOIL REACTION OR ACIDITY	[illegible]	Moderate to strongly acid			Usually strongly acid	Variable	Slightly acid
LAND USE GROUP	[illegible]	[illegible]	[illegible]	Fair to good agricultural land (2)	Nonagricultural land (6)		
CROP ADAPTABILITY AND UTILIZATION	[illegible]	[illegible]. Mixed farming [illegible]	[illegible]	Well suited to hay, grain, grassland and field roots. Mixed farming and dairying	Under natural vegetation	Unsuited to agricultural use although some marsh hay occasionally cut on the better drained areas. Under natural vegetation	Non-agricultural soil. Sparsely covered with natural vegetation
MAIN SOIL PROBLEMS	Drainage	[illegible]	[illegible]	Soil fertility, drainage and erosion	Drainage		Drifting. Low moisture holding capacity

.AND

LEGEND

ZONE: Podsol, Leached strongly acid soils

SOIL SERIES AND NAME	Alberry fine sandy loam	Charlottetown fine sandy loam	Culloden sandy loam	Haliburton fine sandy loam	Pownal fine sandy loam	Dunstaffnage sandy loam	Kildare sandy loam
MAP COLOUR AND SYMBOL	Aal	Chfsl	Csl	Hfsl	Pfsl	Dsl	Ksl
ACREAGE	115,400	560,000	192,960	27,500	4,000	33,560	18,210
PER CENT OF TOTAL AREA	23.1	[illegible]	13.0	2.0	0.3	2.5	1.3
DESCRIPTION OF SURFACE SOIL AND SUBSOIL	Light brown to brown fine sandy loam over weak brownish red sandy loam to fine sandy loam. Friable to very friable	Light brown to brown fine sandy loam to very fine sandy loam over weak brownish-red fine sandy loam to very fine sandy loam. Friable to firm	Greyish brown to light brown sandy loam to light fine sandy loam over weak brownish red sandy loam. Very friable porous. Variable gravel	Brown to dark brown fine sandy loam over dusky reddish brown fine sandy loam. Friable	Brown to dark brown fine sandy loam to loam over dark red very fine sandy loam with lenses of clay	Greyish to light brown sandy loam to light fine sandy loam over light brown sandy loam. Loose gravelly and porous	Grey, dark grey and grey brown loamy fine sand to light fine sandy loam over brown to reddish brown sandy loam. Loose, porous
PARENT MATERIAL	Brownish red sandy loam to fine sandy clay loam derived mainly from brown and red sandstone material	Red fine sandy loam to fine sandy clay loam derived from red sandstone shale and conglomerate	Brownish red sandy loam gravelly to stony derived mainly from brown and red sandstone material	Dusky reddish brown fine sandy loam derived largely from soft dusky red sandy material highly micaceous	Similar to Charlottetown series some modification by water action	Light brown gravelly to stony water worked sandstone and conglomerate material	Weakly sorted sandy water-worked materials. Loose and porous. Bed rock or till at 12 to 36 inches
TOPOGRAPHY	Undulating to gently rolling			Undulating		Undulating to gently rolling (Kames and Eskers)	Gently undulating to nearly level
NATURAL DRAINAGE	Well drained, surface run-off medium to high, subsoil drainage moderate		Rapid to excessive surface run-off medium to high subsoil drainage rapid	Well drained, surface run-off moderate to high. Subsoil drainage moderate to rapid	Moderately well drained, surface run-off medium, subsoil drainage moderate, tends to be slow in places	Excessive. Surface run-off medium to high. Subsoil drainage very rapid	Well drained to excessive. Medium surface run-off and moderate to rapid subsoil drainage
SOIL REACTION OR ACIDITY	Strongly acid			Moderately acid	Variable	Strongly acid	Moderately to strongly acid
LAND USE GROUP	Good agricultural land generally (1)* [illegible] per cent consists of marginal (4) to non agricultural land (6) because of unfavourable topography and susceptibility to erosion		Fair to marginal (3) agricultural land generally with [illegible] per cent non agricultural land (6)	Fair to good agricultural land (2)		Sub-marginal land (5)	Fair to marginal agricultural land (3)
CROP ADAPTABILITY AND UTILIZATION	Suitable to wide range of crops. Largely under cultivation, mixed farming, dairying and potatoes. Main crops: clover and timothy hay, oats, barley, turnips and potatoes		Restricted crop adaptability [illegible] grassland soil. Large proportion under [illegible] or blueberry barrens. Mixed farming, dairying and potatoes. Main crops: oats, hay, and clover hay, field roots and potatoes	Crop adaptability and utilization similar to Charlottetown series but not quite as good a grassland soil. Soil moisture conditions limiting factor	Well suited to hay, pasture and grain. Practically all under cultivation. Mixed farming and dairying	Restricted crop adaptability, poor grassland. Largely under forest or blueberry barrens. Best suited to forest	Narrow crop adaptability range. Fair potato soil, poor grassland soil. Considerable acreage cleared. Mixed farming and potatoes
MAIN SOIL PROBLEMS	Soil fertility and erosion		Soil fertility, erosion and low moisture-holding capacity	Soil fertility and low moisture holding capacity	Soil fertility and drainage	Soil fertility, low moisture-holding capacity	

Compiled, drawn and published by the Experimental Farms Service, Ottawa, 1950, from b...
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