AN ABSTRACT OF THE THESIS OF

Theodore Rosario for the M.S. in Horticulture
(Name) (Degree) (Major)

Date thesis is presented May 15, 1963

Title EFFECTS OF BORON APPLICATIONS ON GROWTH, YIELD, AND BORON CONTENT OF SNAP BEANS

Abstract approved ______________________
(Major Professor)

An investigation of the effects of soil and foliar applications of boron and of time of foliar application of boron on growth, yield, and boron content of bush snap beans was made during the 1962 growing season. This study was conducted at two locations: Corvallis and Aurora, Oregon.

Yield, dry weight, and boron content were computed on the individual plot basis, and results were statistically analyzed. Data were also collected on sieve size distribution of pods and percent pod set. Rates of zero, one, and two pounds of boron per acre were applied to the soil, and the foliar rates consisted of 0, 10, 50, 100, 250, 500, and 1,000 ppm boron.

Applications of boron to the soil in general resulted in a slight decrease in yield of snap beans. Foliar applications of boron followed an erratic pattern, slightly increasing yield in one location and decreasing it at the other. Foliar rates of 250 and 500 ppm boron applied under a combined early-late foliar application resulted in the largest decrease in yield of snap

beans, although the effects of boron applications were not statistically significant.

Boron applications decreased the dry weight of the above-ground portion of bean plants at one location and increased dry weights at the other. However, boron applications did not significantly affect dry weight of snap beans.

Soil applied boron produced a statistically significant increase in boron content of bean plants, irrespective of the time of sampling. An earlier sampling made prior to bloom showed that boron content of bean plants was higher at this stage of growth than at full bloom. Foliar applications of boron consistently increased boron content of bean plants. Boron content of plants at bloom ranged from approximately 22 to 50 ppm at Corvallis and from 20 to 35 at Aurora.

Because no toxic effects were observed as a result of boron applications to the soil, it is believed that the soil boron rates used in this experiment were within the range of tolerance of snap beans to boron. No toxicity effects due to foliar applications of boron were observed when rates below 250 ppm boron were applied.

Neither percent pod set nor sieve size distribution were significantly affected by the boron levels used in this experiment. The relationship of the results of this study to reports of other work is discussed.

EFFECTS OF BORON APPLICATIONS ON GROWTH, YIELD, AND BORON CONTENT OF SNAP BEANS

by

THEODORE ROSARIO

A THESIS

submitted to

OREGON STATE UNIVERSITY

in partial fulfillment of
the requirements for the
degree of

MASTER OF SCIENCE

June 1963

APPROVED:

Associate Professor of Horticulture

In Charge of Major

Head of Department of Horticulture

Dean of Graduate School

Date thesis is presented May 15, 1963

Typed by Marcia Holcombe

ACKNOWLEDGEMENTS

The author wishes to express his very sincere and deep appreciation to his major professor, Dr. Harry J. Mack, for his inspiring guidance, continuous encouragement, and invaluable assistance during this study.

Appreciation is also due to Dr. L. Alban for his kind and thoughtful advice as my minor professor, to Dr. O. C. Compton for the use of the plant analysis laboratory facilities, and to Mrs. Jo Ann Plant for her helpful assistance in explaining the laboratory procedures.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDIX TABLES

EFFECTS OF BORON APPLICATIONS ON GROWTH, YIELD, AND BORON CONTENT OF SNAP BEANS.

INTRODUCTION

The snap bean is one of Oregon's major processing crops and is the most valuable vegetable crop. The production of this crop is concentrated in the Willamette Valley where good soil and an abundant water supply, in addition to long, clear, relatively cool summer days and cool nights provide an excellent environment for its optimum development.

Because of its high significance to the agricultural economy of this state, this crop has received special attention. Considerable time and resources have been dedicated to the study and development of the best cultural practices which would result in the production of optimum yields and high quality product. Also, research work has been conducted on the nutritional needs of the snap bean and how to best supply these needs to insure maximum returns to the producers and a high quality product to the consumer.

The Willamette Valley produces several economically important vegetable crops in addition to snap beans. The quality of some of these crops such as table beets, broccoli, and cauliflower is directly dependent on an ample supply of boron. Since certain soils in the Willamette Valley do not contain enough boron to satisfy the needs of these crops, growers supplement the existing soil levels with applications of boron. Applications as high as eight to ten pounds of boron per acre annually are common on some of the crops listed above.

Often these boron tolerant crops are followed by so-called "boron sensitive" crops, such as snap beans. With relatively high annual applications of boron some concern has originated among growers about the potential injury to boron sensitive crops arising from soil accumulations of boron. Certain phases of this problem have been investigated.

However, many of the soils on which snap beans are grown have not received applications of boron fertilizer and consequently are low in available boron. The purpose of the present study was to further investigate the effects of boron applications on snap beans. The effects of soil and foliar applications of boron on the yield, grades, dry weights and boron content of bush beans were investigated in replicated field plots at two locations. Boron rates used were thought to be in a range in which yield response might be obtained. Plant analysis afforded the opportunity of studying the effects of boron applications on the boron content of bean plants and of determining, which levels, if any, were detrimental to plant growth.

It was the hope that results from this investigation would further elucidate the complex problem of response or tolerance to boron of the snap bean, which is generally classified as a boron-sensitive crop.

REVIEW OF LITERATURE

Boron occurs in nature combined with oxygen. It is estimated that boron constitutes less than 0.001 percent of the earth's crust; however, it is widely distributed. It is found as orthoboric acid, H_3BO_3, in volcanic regions, and as borates, such as borax $Na_2B_4O_7.10H_2O$, Kernite, $Na_2B_4O_7.4H_2O$, Colemanite, $Ca_2B_6O_{11}.5H_2O$, in dry lake regions, especially in the desert areas of Southern California. (36, p. 398)

History

The early work on boron and its relation to agriculture has been comprehensively reviewed by several investigators. Dennis (12, Vol. 32 p. 58-69) and Naftel (35, Vol. 89, p. 1-26) extensively reviewed the early history of boron and its applications to agriculture up to 1938. There seems to be complete agreement among boron literature reviewers as to the fact that boron was first discovered as a constituent of the mineral composition of plants by Wittstein and Apoiger in 1857. In 1890 Callison corroborated Wittstein and Apoiger's findings and postulated that boron is universally distributed among most plant species. Agulhon (1, 150 p. 288-291) in experimenting with boron, discovered an increase in dry weights of radishes, oak, and wheat grown in sand cultures to which boron had been added. Maze in 1915 proved the essentiality of boron for the development and reproduction of corn.

Warrington (47, Vol. 37, p. 629-672) showed that boric acid is toxic to beans, when it is applied at a ratio of 1: 5,000 in water cultures; however, smaller amounts of boric acid added to the growing medium were beneficial. In 1926 Warrington (48, Vol. 40 p. 27-42) also showed that bean plants failed to complete their life cycles in water and sand cultures from which boron was excluded. Boron was shown to be associated with nutrient translocation in the tomato plant by Johnsen and Dore (24, Vol. 6, p. 324-325).

McMurtrey (31, Vol. 38, p. 371-380) in working with tobacco, revealed that boron is required for normal development of this plant. A year later, Johnson and Fisher (25, Vol. 5, p. 387-392) in studying some aspects of the tomato plant nutrition concluded that boron is indispensable for normal growth of this plant, thus corroborating earlier findings reported by Johnson and Dore (24). Brandenburg (6, Vol. 3, p. 499-517) demonstrated the significance of boron deficiency in agricultural practice by associating it as the cause of heart rot of sugar beets.

Boas (5, Vol. 1, p. 393) made reference to the effect of boron on table beets and showed that applications of borax and boric acid counteracted the detrimental effects of drought. The essential role of boron in pollination was ascertained by Schmucker (45, Vol. 23, p. 264-268). This investigator demonstrated that boron inhibits excessive swelling and bursting of pollen tubes; thus, it is required for normal fertilization.

Berger and Truog (4, Vol. 11, p. 540-554) aimed at establishing a correlation between soil boron levels and the boron content of beets grown on them. Their data showed that beet plants from low boron soils contained only 14.5 ppm boron, whereas those grown on the same soils to which boron was added contained 24 ppm boron.

Purvis (42, Vol. 4, p. 316-321) showed that carbohydrates tend to accumulate in the leaves of boron-deficient plants, and at the same time a decrease in carbohydrate in the storage organs took place. The author explained this phenomenon in terms of the inability of the plant to convert carbohydrates into proteins, or to translocate carbohydrates from the leaves to other organs of the plant. This is believed to be due to disruption of the conducting tissue which results from reduced rate of protein metabolism. Dennis and Dennis (13, p. 125) suggested that boron may bring about a more economical use of nitrogen, since supplying boron to boron-deficient plants usually results in an increase in plant growth. Schuster (46, Vol. 29, p. 63-68) postulated that adequate boron levels are essential for the effective utilization of other nutrient elements. He further suggested that shortages in one or more of the required elements may mask the need for boron or may accentuate boron deficiency.

Residual Effects of Boron Applications

Wear (50, p. 1-20) conducted an extensive study of the boron requirements of crops on Alabama soils and reported that borax added to sandy soils was rapidly leached down. However, borax applications to fine texture soils remained in the upper surface foot and tended to accumulate there over a long period of time. His results reveal that the fate of boron applications is to a great extent dependent on the soil texture. Wilson et al. (53, Vol. 43, p. 363-367) applied 40 pounds borax per acre to a Norfolk sandy loam and found that it disappeared almost completely from the surface eight inches within six months. It was observed by these investigators that applications of borax at a rate of 30 pounds per acre annually for six years to Norfolk and Cecil sandy loam soils resulted in accumulation of the soluble boron in the 12-to-36 inch layer of soil. In the Cecil clay boron accumulation mainly occurred in the top six inches.

Similar results were reported by Wear (49, Vol. 48, p. 132-134) for six Alabama soils who found that boron did not accumulate on the surface 12 inches of coarse textured soils but did accumulate in the surface of fine textured soils. Monk (32, Vol. 35, p. 22-32) investigating the movement of boron in the soil, applied 300, 600, and 1200 pounds of borax per acre to a fine sandy loam in New Zealand and reported that approximately 85 percent of the initial borax application could not be accounted for; probably it had moved down into the lower soil layers.

Jones and Scarseth (26, Vol. 57, p. 15-24) suggested that it is possible to add a greater amount of boron to alkaline or limed soils without causing injury or toxic effects than to an acid soil. Colwell and Cummings (11, Vol. 57, p. 37-22) made reference to the effect that there may exist an equilibrium mixture of several ionic species of orthoborates, metaborates, and tetraborates, some of which are relatively unstable in aqueous solution. They further suggested that the same soil conditions which favor boron deficiency also encourage the formation of condensed borates. Both total and soluble boron were shown by Hernandez and Shive (19, Vol. 30, p. 253-291) to be largely dependent on the calcium concentration of the substrate.

Thus, it would appear from the results obtained by the investigators here cited, that the danger to sensitive crops which follow crops requiring boron applications is not as serious as it has previously appeared to be. Wear (16) has concluded that boron availability is affected by the following soil factors: pH, texture, exchange capacity, and organic matter content. It is also known that temperature and moisture content of the soil influence boron availability to a great extent.

Effects of Boron Applications on Certain Crops

Purvis and Hanna (43, Vol. 105, p. 1719-1742) reported that at least sixteen vegetable crops in Eastern Virginia responded favorably to field application of boron. Eaton (15, Vol. 69, p. 237-277) grew 58 different crop varieties in sand cultures with boron levels ranging from 0.03 to 25.00 ppm boron. His data show that approximately 25 percent of the plants made their greatest growth under the trace boron concentration and others responded favorably to 1 ppm or more boron. However, the growth of a number of varieties was stimulated by boron rates as high as 10 and 15 ppm.

The essentiality of boron for seed production in most legumes has been established by several investigators among whom are Grizzard and Mathews (17, Vol. 34, p. 365-368), Hutcheson and Cocke (22, p. 1-20) and Peland, _et al_. (40, Vol. 57, p. 75-84). These and other investigators indicated that seed production by most legumes is dependent upon a sufficient and steady supply of boron. Burrell, (9, Vol. 71, p. 20-25) in working with apples, Rogers (44, Vol. 61, p. 119-122) in investigating the cause of "blossom blast" in pears and Batjer and Thompsom (3, Vol. 54, p. 141-142) also in working with pears, reported markedly improved yields of these crops by foliar applications of boron. Powers (41, Vol. 4, p. 316-321) obtained good control of beet canker with an application of 30 pounds per acre of boric acid to several low-boron Oregon soils. Similarly, the incidence of cracked stem in celery and yellow top in alfalfa were significantly decreased by applying this borax rate to the soil. White-Stevens (52, Vol. 39, p. 361) observed that under Long Island conditions up to 20 pounds of borax were required for the production of beets, rutabagas, and most crucifers. Peas and potatoes grown on these low-boron soils responded well to five-pound borax applications but yield was depressed when this rate was exceeded.

Yamaguchi and Minges (55, Vol. 68, p. 318-323) reported that soil applications of boron sometimes did not help in controlling brown checking in celery, but spraying the celery plants with boric acid solution controlled brown checking. Hoagland and Snyder (20, Vol. 30, p. 288-294) showed that strawberry plants grown in culture solutions without boron developed striking deficiency symptoms. Leaves of boron-deficient plants were abnormally small, deformed and cupped upward. Muhr (34, Vol. 54, p. 55-65) grew several root crops and cereals in a boron-deficient media and in boron-sufficient media to determine boron deficiency symptoms in these crops. His data reveal that an insufficient supply of boron for root crops was evidenced by distortion of the central leaves, by formation of numerous small leaves and by breakdown of the root tissue cells. The cereals matured later and failed to develop normal seeds when boron was lacking.

Alexander (2, Vol. 103, p. 475-491) studied boron deficiency symptoms in squash and observed a brittleness in the above-ground portions of the plant, together with a stunted and discolored root system. An enlargement and collapse in the region of cell division, hypertrophy of the xylem parenchyma and a lack of geotropic response were also reported. Hussin (21, p. 98-100) investigated the relationship between crown gall development and boron supply and found boron to be essential for the development of crown gall in cherry trees and tomato plants.

Effects of Boron Applications on Beans

Although the functions and effects of boron on almost every economically important crop have been investigated, the boron literature on snap beans is very limited. The reason for this apparent irrelevancy is perhaps due to the fact that beans have long been considered as a very sensitive crop with respect to boron; and therefore, research work on this crop has been limited.

In 1920, Morse (33, p. 89-120) at the Maine Experimental Station, found that 4.40 pounds of anhydrous borax per acre, applied in the drills caused severe injury to beans. A year later, Neller and Morse (37, Vol. 12, 79-105) stated that three pounds of anhydrous borax per acre was the largest amount that could be applied without causing damage to beans. Warrington (5,6) showed that applications of boric acid at a rate of 1: 5,000 or higher in water cultures produced toxic effects on bean plants. Three years later this author reported that although the bean is rather a boron sensitive crop, plants failed to grow and develop to their fullest potential if boron was lacking from the growing medium. Brenchly and Thornton (7, Vol. 98, p. 379-399) suggested that boron was necessary for the development of the vascular system between the roots and nodules of the bean plants. Callings (10, Vol. 23, p. 83-105) reported in 1927 that an application of one pound of boron per acre in the form of boric acid, or potassium borate, or of 2.50 pounds of borax is sufficient to decrease the dry weights during the seeding stage. Nevertheless, these rates did not decrease the dry weights of fully developed plants -- perhaps due to a dilution effect of the element with increasing size of the plants.

Eaton (15, Vol. 69, p. 237-277) classified the kidney bean as a boron sensitive crop, requiring 0.50 ppm or less boron for optimum development. However, he stated, "The data provide substantial basis for the conclusion that there is considerable overlapping between injurious and beneficial effects of boron within plants, inasmuch as mild to marked leaf injury was observed in 19 of the 72 plants studied at or below the substrate concentration that resulted in greatest growth".

Owen (38, Vol. 35, p. 119-122) reported that manure containing 12 pounds borax per acre and banded close to bean seed, produced a bright yellow coloration of the first leaves, but apart from the occurance of this disorder, no further detrimental effect was observed. In view of this phenomenon, a second experiment was carried out to determine at which level borax becomes toxic to beans when banded near the seed. The rates applied were: 0, 12, 25, 50, and 100 pounds borax per acre. All levels of borax resulted in a marked yellowing of the seedlings. Application of 25 pounds of borax per acre depressed markedly both stand and yield. The leaves, irrespective of the stage of growth at which they were sampled, contained the highest boron concentrations.

Huyskes (23, Vol. 46, p. 133-139) concluded from observations on trial plots that the application of 40-50 pounds of borax per acre, while preventing the incidence of beet heartrot, caused typical damage on French beans. Wester and Magruder (51, Vol. 38, p. 472-474) showed that side-dress applications of 10 to 15 pounds boric acid to lima beans prior to bloom significantly increased the yield but did not affect plant growth as determined by fresh weights of the plants. These investigators pointed out that plants receiving no boron application showed no symptoms of boron deficiency at any time during the extent of the experiment. Bountiful beans were used as indicator plants by Jordan (27, p. 59-61) during his study of the boron status of different Oregon soils. Under greenhouse conditions, this author reports the germination of bean seeds planted in a Melbourne silty clay loam which averaged 200 ppm boron. However, the seedlings died soon after germination. He further reports that a crop of bean plants, although exhibiting toxicity symptoms, was obtained from a soil containing 40 ppm boron. Yet, under these same growing conditions, bean plants exhibited symptoms of boron toxicity when grown in media which contained as low as 1.10 ppm boron. Jordan classified the bean plant as a semi-tolerant crop with respect to boron.

Brown (8, p. 1-13) reports that while small amounts of boron, when placed in contact or near the seed, could be detrimental to it, broadcast applications of borax as high as 10 pounds per acre, did not in any manner affect the development of bean plants. Plants were only slightly injured by broadcast applications of 20 pounds borax per acre. However, he classified beans as a very sensitive crop to boron. Page and Paden (39, Vol. 14, p. 253-259) studied the differential response of snap beans and certain other crops to varying rates of calcium and sodium borates on three soil types and found that the yields of snap beans were lower and boron content of the leaves higher when a sodium borate was applied instead of a calcium borate. Lingle and Carolus (29, Vol. 71, p. 507-515) conducted an experiment aimed at determining the effects of boron and sodium levels in the soil and their influence on the levels of these two elements within the plant. They reported that sodium depressed the boron levels of eight out of the fourteen crops investigated. Furthermore, no crop showed a significant increase in boron as a result of sodium applications.

Hatcher, et al.(18, Vol. 88, p. 98-100) in an effort to determine whether or not bean plants responded to absorbed boron, grew bean plants on three soils having a wide range of boron absorptive capacities. They found that beans respond only to boron in solution and are not influenced by adsorbed boron. These findings perhaps could explain why the availability of boron in the soil is to a great extent dependent on the exchange capacity of the soil as reported by several investigators.

MATERIALS AND METHODS

The experiments were conducted during the 1962 growing season in two different locations: (1) at the Oregon State University Vegetable Crops Farm near Corvallis, and (2) at the North Willamette Experiment Station, near Aurora, Oregon. The soil at the Vegetable Crops Farm at Corvallis is a Chehalis silt loam. Soil analyses from 0-12 inch depth indicated the following mean values: pH 6.25, 24 ppm phosphorus, 0.50 m.e. potassium, 20.2 m.e. calcium, 7.70 m.e. magnesium per 100 grams soil with a total cation exchange capacity of 30.0 m.e. per 100 grams soil.

The soil type at the North Willamette Station is a sandy loam, mapped as Willamette, with soil test values as follows: pH 5.95, 46 ppm phosphorus, 0.59 m.e. potassium, 7.80 m.e. calcium, 1.80 m.e. magnesium per 100 grams soil with a total cation exchange capacity of 16.0 m.e. per 100 grams soil. Both of these soils are widely used for production of snap beans in Western Oregon.

Tendercrop, a bush type snap bean, was used at both locations. The seed was mechanically planted and the fertilizer was banded at planting time. The amounts of fertilizer used were considered to be sufficient for optimum yield. At Corvallis a rate of 500 pounds 8-24-8 per acre was used, whereas at Aurora a rate of 250 pounds 16-20-0 per acre was applied. The plots were sprinkler irrigated with sufficient water to insure maximum production. The plots were kept free from weeds by weekly hand

and mechanical cultivations. Little insect control was necessary, since no major insect infestation was observed at any time during the course of the experiments.

The Corvallis Experiment

Fifteen foliar boron treatments, superimposed on three soil boron levels, constituted the experiment. Single row plots, 20 feet in length, were used. The plots were equally distributed among the three soil boron levels and arranged in a split plot design with soil boron levels forming main plots and foliar levels forming sub-plots.

The three soil boron levels consisted of adding zero, one, and two pounds of boron per acre to the soil. The same boron-containing material (Solubor) containing 20.5 percent boron was used for both soil and foliar applications. The boron material was mixed with the equivalent of 20 pounds nitrogen per acre as ammonium sulfate and was broadcast by hand. The same amount of ammonium sulfate was applied to the non-boron plots. These materials were thoroughly mixed with the soil a week prior to planting time. The soil boron plots were replicated four times, making a total of twelve, one-fortieth of an acre plots.

The foliar treatments were divided into three categories: early, late, and a combination of early and late applications. The early treatment consisted of applying foliarly once only the following boron rates: 0, 10, 50, 100, and 500 ppm boron.

The late treatment consisted of these same levels, except that an additional treatment of 250 ppm was included. The combined treatment consisted of split early-late applications as follows: 0, 5-5, 25-25, 50-50, 250-250, and 500-500 ppm boron.

The early foliar applications were made June 29, 1962, approximately six weeks after planting. At this time, the early treatment as well as the first portion of the combined treatment were applied. The late treatment and the latter portion of the combined treatment were applied ten days later when the plants were in full bloom. A hand sprayer was used for the application of the material and enough solution was applied to completely wet the plants.

The Aurora Experiment

The same rates of boron application to the soil used at Corvallis were used at Aurora. However, at Aurora both the soil boron as well as the foliar treatments were arranged in a completely randomized block design. The individual plot area was approximately 126.4 square feet or 1/354 acre. Forty-foot long plots were used for yield computations. The foliar applications were different from those at Corvallis, inasmuch as only a combined treatment was applied. The foliar rates were: 10-10, 25-25, 50-50, and 100-100 ppm B. The first foliar application was made July 27, when plants had begun to expand their second trifoliate leaves. The second foliar treatment was applied August 15, when the plants were at early bloom.

Soil Sampling Method

Shortly after planting, soil samples were taken at both experimental areas, using a soil tube. The soil was sampled at a depth of 0-12 inches and a minimum of 12 cores were taken for each plot. Plots receiving no boron were identically sampled as those receiving boron. All samplings obtained from the same soil replication were combined as a sample and analyzed by the Oregon State University Soil Testing Laboratory. Laboratory analysis on the Corvallis soil showed the boron contents for the three soil boron levels (0, 1, and 2 pounds boron per acre) averaged 1.25, 1.50 and 2.11 ppm B. The analysis of the Aurora soil showed the zero soil boron plots contained 0.89 ppm B, the one pound boron per acre plots 1.16 ppm B, and the two pounds boron per acre plots 1.17 ppm B.

The Collection of Plant Samples

Only the above-ground portions of the plants were taken and analyzed. Therefore, all data presented will be concerned with the above-ground portion of the bean plants. All plant samples were collected and analyzed by individual plots. The plants were selected at random from the entire length of the plot and roots were cut off soon after. This procedure was adopted to insure uniformity of the sampling material, since roots often tend to break off and because of this, accurate results are difficult to obtain.

At Corvallis, a plant sampling was made July 9, prior to the second foliar application. Plots belonging to the early and combined treatments had already received a foliar application; those belonging to the late treatment had not yet received any foliar application. However, this sampling was gathered from the early treatment only. Samples of the check treatment were also simultaneously collected. At this time, plants were beginning to bloom. These samples consisted of five plants gathered at random from each plot. The second and third samplings were made July 17, and July 24 at full bloom, and after all foliar treatments had been applied. The fresh weight of the plants was determined immediately after the samples were collected. The number of blossoms per plant was individually determined on both the second and third samplings, shortly after obtaining their fresh weights.

At Aurora, two samplings were made. The first sample was taken when plants had developed the first trifoliate leaf and the second trifoliate was beginning to expand. Five plants per plot were collected approximately a week after the first foliar treatment was applied. Similarly, the second samples gathered August 23, consisted of five plants per plot. The plants were in full bloom and had received the two foliar boron applications. As in the Corvallis experiment, only the above-ground portion of the plant was used for the different determinations. No blossom count was conducted on the Aurora samples.

Preparation of Plant Material

The plant samples were gathered in pre-labeled paper bags, and immediately brought into the laboratory for fresh weight determination and blossom counting. Then, they were placed in forced-draft ovens and dried at a temperature range of 50°-60° C for 60-72 hours. When the plant material was completely dry, the weight of the individual samples was recorded; the dry plant material was ground in a stainless steel Wiley Mill.

The first Corvallis sampling was analyzed separately. The second and third samplings were combined and boron determination was made on plant material representative of both samples. The two Aurora samplings were analyzed for boron content separately on an individual plot basis. Polyethylene bags were used to store the ground samples until such time as the chemical analysis could be performed. Prior to analysis, samples were transferred from the plastic bags into screwtop bottles and placed for four to six hours in the oven at 70° C to insure uniform moisture content of the plant material.

One-half gram of thoroughly mixed plant material was weighed and placed on a porcelain dish. The dish was then transferred to a muffle oven where the sample was ashed at a temperature of 350^{o}-$500^{o}C$ for eight hours, at which time the ashing of the sample had been completed as indicated by the uniform grayish-white color of the ash. Boron concentration was determined by using the colorimetric, simplified curcumin procedure as described by Dible, Truog, and Berger, (14, Vol. 26, p. 412-418).

Yield Data

At Corvallis, beans were hand-picked and the yield recorded on an individual plot basis. When all plots had been harvested, the total yield for each treatment was computed on the ton per acre basis. The beans were picked when it was estimated that 40-50 percent of the pods were seive size four or smaller. Only one picking was done; this to simulate a "once-over" machine harvest. Replications 1 and 2 were harvested on August 1, and replications 3 and 4 were harvested on August 2.

The yields reported represent ungraded pods. To further conform with prevailing commercial practices, the beans were mechanically graded into seven grades or sieve sizes. Percent pod set was determined by separately picking the pods of ten plants per plot, selected at random. These pods were kept in a separate bag, weighed, and counted. After the pods were counted they were added to the pods of corresponding plots. The number of pods produced per plant was used as the basis for computing percent pod set.

At Aurora, the plots were harvested mechanically by a bean picker. Yield data were based on harvest of a single plot 40 feet in length. Enough guard row area was allowed between plots so that the machine would be thoroughly free of pods after the harvesting of each plot. The pods were graded in the same manner as those from the Corvallis experiment. Percent pod set was not determined, since no previous blossom count had been made.

RESULTS

The effects of soil and foliar applications of boron as well as the effects of rate and time of application on yield, grades, dry weight, boron content, and percent pod set of snap bush beans are presented.

Yield is expressed in tons per acre and dry weight is in grams per five-plant sample. Boron content is shown as ppm B. Percentage of each grade is expressed in terms of sieve size and pod set as percent of flowers which produced and developed pods. No data on pod set are presented for the Aurora experiment, since number of blossoms produced by plants was not recorded. Results of the experiments at Corvallis and at Aurora are presented separately.

The Effects of Boron Applications on Bush Beans - Corvallis

Yield: Statistical data on the effects of boron applications on the yield of snap beans are presented in Appendix Table 1. Analysis of variance shows no significant effect on yields by soil or foliar applications of boron. However, when means for foliar treatments at the two pounds soil boron per acre rate were analyzed separately, these data show that only applications of 250-250 and 500-500 ppm boron under the early-late treatment significantly decreased yield at this soil level. Analysis of variance on the effects of application of two pounds boron per acre to the soil on yield of snap beans is presented in Appendix Table 2.

Data on the influence of different levels of soil-applied boron on yield of bush beans are presented in Table 1. These data show that application of rates of zero, one, and two pounds boron did not significantly affect the yield of snap beans. Only a slight decrease of the total yield was observed when two pounds of boron were applied to the soil. The mean yields of the three soil levels were 4.46, 4.45, and 4.35 tons per acre for the zero, one, and two pound-rates, respectively. The mean for the treatment receiving no foliar boron was 4.40 tons per acre.

Effects of soil-applied boron can be compared free from foliar interactions. Plants grown with a rate of one pound soil boron yielded slightly less than those receiving no boron. On the other hand, plants grown at the two pound boron rate yielded higher than either the one pound boron rate or the check treatments. The means of yield obtained for these three soil levels which did not receive foliar applications of boron were 4.33, 4.23, and 4.64 tons per acre for the zero, one, and two pounds soil boron applications, respectively.

Table 1. The Effects of Boron Applications on Yields of Bush Beans, Corvallis.

Tons Per Acre

Time	Foliar Rates (ppm B) 0	10	50	100	250	500	1000
			No boron applied to the soil				
Early	4.33	4.50	4.38	4.56	----	4.70	----
Late	4.33	4.67	4.37	4.81	4.65	4.56	----
Early-Late	4.33	4.60	4.73	4.23	----	4.61	3.98
Means	4.33	4.59	4.49	4.53	4.65	4.62	3.98
			1 lb. boron per acre applied to the soil				
Early	4.23	4.49	3.97	4.65	----	4.59	----
Late	4.23	4.56	4.46	4.56	4.60	4.46	----
Early-Late	4.23	4.44	4.66	4.51	----	4.40	4.41
Means	4.23	4.50	4.36	4.57	4.60	4.48	4.41
			2 lbs. boron per acre applied to the soil				
Early	4.64	4.23	4.65	4.19	----	3.06	----
Late	4.64	5.00	4.38	5.13	4.37	3.84	----
Early-Late	4.64	4.92	4.55	4.59	----	3.78	3.99
Means	4.64	4.72	4.53	4.64	4.37	3.56	3.99

Yield data presented in Table 2 indicate that foliar-applied boron did not significantly influence the total yield of bush beans. However, the foliar application of 10 ppm boron exerted a stimulatory effect on total yield of beans under all three times of treatments. This stimulatory effect was most marked for the late treatment, followed in decreasing magnitude by the early-late and early treatments. Foliar sprays containing 50 ppm boron slightly increased yields above those obtained from the check plots.

The application of 100 ppm boron decreased the yield below that produced by the check treatment for plants under the early treatment. The yield produced by the combination treatment, when receiving 100 ppm boron, was only slightly higher than from the 500 ppm boron treatment. The highest yield recorded for all foliar concentrations was obtained by applying 100 ppm boron during the late treatment.

When a rate of 500 ppm boron was foliarly applied, a reduction in yield below that obtained for the check was obtained. This reduction was most marked under the early treatment; the yield of which was also depressed by the application of 100 ppm boron.

Table 2. Effects of Time and Rates of Foliar Applications of Boron on Yield of Bush Beans - Corvallis.

	Tons Per Acre			
	Time of Application			
Foliar Rates	Early	Late	Early-Late	Means
ppm B				
0	4.40	4.40	4.40	4.40
10	4.44	4.75	4.62	4.60
50	4.45	4.40	4.53	4.46
100	4.36	4.83	4.56	4.58
500	3.88	4.29	4.28	4.15
Means	4.31	4.53	4.48	

Highest yields were obtained under the late treatment, followed in decreasing order by the combined early-late and early treatments, respectively. However, the data reveal no significant effect of time of application on the yield of bush beans. Nevertheless, these data seem to point out that the early treatment had a slightly inhibitory effect on yield and that when these same boron levels were applied at a later date, a small stimulatory effect on the total production of beans resulted.

Grades: Data on the influence of boron applications on bush bean grades are presented in Table 3. Only pods from the zero and two pounds rates of soil boron treatments were graded. These data show grades differed only very slightly among treatments and did not seem to be affected by either foliar or soil applications of boron, when compared to the check treatment. Also, it would appear that time of application did not affect grades of snap beans. Data on the effects of rates of foliar applications of boron on bush bean grades are presented in Table 4. These data indicate that grades of snap beans were not materially affected by the boron rates or timing of application.

Table 3. Effects of Boron Applications on Sieve Size of Grades of Bush Beans, Corvallis.

Percentage of each grade as indicated by sieve sizes

Time	1-2	3	4	5	6	7
		No boron applied to the soil				
Check	7.7	13.3	19.9	42.3	15.7	1.1
Early	7.8	12.7	20.0	41.0	17.1	1.6
Late	8.2	12.3	20.6	39.6	18.0	1.2
Early-Late	7.3	12.4	20.2	41.3	17.4	1.3
*Means	7.8	12.5	20.3	40.6	17.5	1.4
		2 lbs. boron per acre applied to the soil				
Check	10.1	13.1	20.0	37.8	17.9	1.1
Early	7.8	13.9	21.6	40.3	15.4	1.1
Late	7.9	12.9	20.5	41.5	16.1	1.3
Early-Late	7.7	13.1	21.5	41.4	14.3	1.2
*Means	7.8	13.3	21.5	41.1	15.3	1.2

*Means do not include check treatments

Table 4. Effects of Rates of Foliar Applications of Boron on Bush Bean Sieve Size Grades, Corvallis.

Percentage of each grade as indicated by sieve sizes

Foliar Rates ppm B	1-2	3	4	5	6	7
			No boron applied to the soil			
0	7.7	13.3	19.9	42.3	15.7	1.1
10	6.4	11.9	19.0	39.8	20.0	1.4
50	8.4	13.0	21.1	40.2	16.0	1.2
100	6.8	12.8	20.8	41.1	16.3	1.2
250	7.9	11.9	21.1	38.1	18.9	1.6
500	8.0	13.3	20.4	42.1	15.8	1.5
1000	7.8	12.4	19.2	41.6	17.8	1.2
			2 lbs. boron per acre applied to the soil			
0	10.1	13.1	20.0	37.8	17.9	1.1
10	7.4	12.7	21.3	41.0	16.2	1.3
50	8.3	14.0	21.6	40.0	15.3	0.8
100	8.3	13.3	20.7	40.5	15.4	1.5
250	7.2	13.1	21.0	43.3	14.1	1.3
500	7.4	12.8	22.2	42.0	14.5	1.1
1000	7.9	12.9	21.8	41.4	14.7	1.5

Dry Weight: Table 5 presents dry weight data which reveal that when plants received no foliar boron the application of one and two pounds of boron per acre to the soil resulted in an increase in the dry weights of bean plants. At rates of one and two pounds boron applied to the soil, foliar applications of boron, in general, reduced dry weights. Over-all effects of soil-applied boron on dry weights (all foliar treatments combined) of bean plants are indicated by means of 131.5, 127.7, and 120.7 grams for the zero, one and two pounds boron levels, respectively. These means show the existence of a definite trend of decreasing dry weights with increasing soil boron concentration.

Data regarding the effect of time and rates of foliar applications of boron on the dry weight of snap beans are presented in Table 6. Means of dry weights were lowest for plants receiving the early foliar treatment, followed in increasing order by the early-late and late treatments, respectively.

Analysis of variance on the effects of boron application on dry weight of bush bean plants is presented in Appendix Table 3. These analyses show no significant effect on dry weight due to either soil or foliar-applied boron.

Table 5. Effect of Boron Applications on the Dry Weights of Bush Bean Plants, Corvallis.

Dry Weight in Grams per Five Plant Sample

	Foliar Treatments (ppm B)						
Time	0	10	50	100	250	500	1000
			No boron applied to the soil				
Early	119.0	143.5	138.8	127.0	-----	110.8	-----
Late	119.0	132.0	127.5	128.8	130.8	133.8	-----
Early-Late	119.0	135.8	130.5	117.8	-----	144.0	146.8
Means	119.0	137.1	132.3	124.5	130.8	129.5	146.8
			1 lb. boron per acre applied to the soil				
Early	133.8	116.5	110.3	135.5	-----	136.5	-----
Late	133.8	136.5	126.0	118.5	123.5	119.0	-----
Early-Late	113.8	133.8	130.5	117.5	-----	115.8	137.8
Means	133.8	128.9	122.3	123.8	123.5	123.5	137.8
			2 lbs. boron per acre applied to the soil				
Early	134.0	113.8	122.0	115.2	-----	128.5	-----
Late	134.0	127.0	128.5	130.0	116.3	116.3	100.3
Early-Late	134.0	121.3	116.3	123.8	-----	113.3	114.5
Means	134.0	120.7	122.3	123.0	116.3	114.3	114.5

Table 6. Effects of Time and Rates of Foliar Applications of Boron on the Dry Weight of Bush Beans, Corvallis.

Dry Weight in Grams per Five Plant Sample

Foliar Rates	Time of Application			Means
	Early	Late	Early-Late	
ppm B				
0	128.9	128.9	128.9	128.9
10	124.6	131.8	130.3	128.9
50	123.7	127.3	125.8	125.6
100	125.9	125.8	119.7	123.8
500	125.6	117.7	124.4	122.5
Means	125.7	126.3	125.8	

A further study of these data reveal that all foliar concentrations applied during the early treatments consistently resulted in a decrease of the dry weights of plants. When the data for the late and early-late treatments are inspected, it can be observed that all foliar concentrations applied, except the 10 ppm boron, reduced dry weights of snap bean plants.

Upon consideration of the means for all foliar levels, all concentrations, except the 10 ppm boron, decreased the dry weight content below that of the check treatment.

Boron Content: Data on boron content of bean plants collected during the first sampling are presented in Table 7. These samples were collected July 9, one week after receiving the early foliar treatment and the plants were at full bloom. It is interesting to observe the distinct effect that soil boron application exerted on the boron content of the bean plants. The data show that there is a positive relationship between soil boron levels and boron content of plants at this stage of development. Under all soil treatments, increasing the foliar rates of boron resulted in a marked increase in boron content of the plants.

Table 7. Effects of Boron Applications on Boron Content of Bush Beans - Early Sampling, Corvallis.

	Boron Content in ppm B			
	Pounds boron per acre			
Foliar Rates ppm	0	1	2	Means
0	28.5	27.4	34.3	30.1
10	30.7	31.9	36.6	33.1
50	31.9	34.3	45.7	37.3
100	33.1	37.8	51.4	40.8
500	66.0	67.9	67.9	67.3
Means	38.0	41.5	47.2	

Data showing the influence of boron applications on boron content of bean plants of the major sampling are presented in Table 8. The addition of boron to the soil consistently resulted in an increase in the boron content of the plants. When means for the three soil boron levels are considered, the data show an increase of approximately 3 ppm B in the boron content for plants at the one pound soil boron rate, while the application of two pounds boron to the soil increased boron content only about one ppm above the boron content of plants grown at the one pound rate of soil boron.

Effects of foliar boron on the boron concentration of bean plants are presented in Table 8. The table shows that the plants increased in boron content as foliar rates of boron were increased up to 500 ppm, irrespective of the soil level on which they were grown.

Analysis of variance of the effects of boron application on boron content of bean plants is presented in Appendix Table 4. Boron content of plants was significantly increased by soil and foliar applications of boron.

Table 8. Effects of Boron Applications on Boron Content of Bean Plants, Corvallis.

Boron Content in ppm B

	Foliar Rates (ppm B)						
Time	0	10	50	100	250	500	1000
			No boron applied to the soil				
Early	22.3	26.9	28.0	29.9	----	36.4	----
Late	22.3	26.2	27.4	31.6	34.6	42.5	----
Early-Late	22.3	28.8	29.3	28.8	----	43.8	48.3
Means	22.3	27.3	28.2	30.1	34.6	40.9	48.3
			1 lb. boron per acre applied to the soil				
Early	25.3	27.7	29.8	30.2	----	41.9	----
Late	25.3	29.8	30.2	33.4	38.3	49.8	----
Early-Late	25.3	30.8	30.0	32.7	----	53.5	55.0
Means	25.3	28.5	29.4	32.1	38.3	48.5	53.0
			2 lbs. boron per acre applied to the soil				
Early	26.7	30.5	32.5	32.0	----	43.1	----
Late	26.7	30.8	28.8	43.3	39.6	53.8	----
Early-Late	26.7	31.4	31.9	34.3	----	49.2	50.0
Means	26.7	30.9	31.1	33.5	39.6	48.7	50.0

L.S.D. Individual treatments .05 = 1.62

.01 = 2.17

Data on the effects of time of application and concentration of boron foliar sprays on the boron content of bean plants are presented in Table 9. Chemical analysis show plants contained less boron when receiving the early treatment than they did under the late and combination treatments. When the means for foliar rates are considered, the boron content of plants was increased almost two-fold when rates were increased from zero to 500 ppm boron.

Table 9. Effects of Time and Rates of Boron Applications on Boron Content of Bush Beans, Corvallis.

Boron Content in ppm B

Foliar Rates	Time of Applications			
ppm B	Early	Late	Early-Late	Means
0	24.8	24.8	24.8	24.8
10	28.4	28.0	30.3	28.9
50	30.1	28.2	30.4	29.6
100	30.7	33.1	31.9	31.9
500	40.5	52.0	48.8	47.1
Means	32.4	35.3	35.3	

L.S.D. Means - Foliar Rates .01 = 3.3

Pod Set: In Appendix Table 5 data are presented on the effects of boron applications on percent pod set of snap bush beans. No definite trend in percent pod set resulted as a consequence of boron applications to the soil. When no boron was applied to the soil, the mean percent pod set was 22.7; when a rate of one pound of boron per acre was added to the soil the mean percent pod set was 20.8. The application to the soil of two pounds of boron per acre resulted in a mean percent pod set of 23.4.

In general, foliar applications of boron slightly increased the percent pod set above that obtained from the check treatment.

Table 10. Effect of Boron Applications on Yield of Bush Bean, Aurora.

Tons per Acre

Foliar Rates	Soil Rates of Boron Per Acre			Means of Foliar
ppm B	0	1 lb.	2 lbs.	Rates
0	4.72	4.52	4.69	4.64
10-10	4.46	4.43	4.27	4.39
25-25	4.45	4.39	4.54	4.46
50-50	4.96	4.57	4.82	4.79
100-100	4.58	4.56	4.52	4.55
Means for Soil Levels	4.63	4.49	4.57	

The Effects of Boron Applications on Bush Beans - Aurora

Yield: Yield data of snap beans at Aurora are presented in Table 10. The means for the yields obtained from the three soil boron levels were 4.63, 4.49, and 4.57 tons per acre for the zero, one, and two pounds per acre boron treatments, respectively.

Trends in yield resulting from foliar applications of boron were not consistent. It is of interest to observe that while yields were depressed below that of the check treatment by the two lowest foliar concentrations applied, 10-10 and 25-25 ppm B, the application of 50-50 ppm B, on the other hand, had a relative stimulatory effect on yield. Highest yields for all three soil levels were recorded for plots receiving the 50-50 ppm B foliar application. All three soil treatments yielded approximately the same under the 100-100 ppm B foliar treatment. These differences were not statistically significant, since analysis of variance of yield data (Appendix Table 6) show boron applications did not significantly affect yield of bush beans.

Grades: Inspection of the sieve size grades in Table 11 show that boron applications had no appreciable influence on snap bean grades. The means for three soil and five foliar treatments demonstrate that only very slight differences existed among treatments.

Table 11. Effects of Boron Applications on Snap Beans Sieve Size Grades, Aurora.

Foliar Rates ppm B	Percentage of each grade as indicated by sieve sizes 1-2-3	4	5	6	7 & Culls
	No boron applied to the soil				
0	24	17	35	20	4
10-10	23	17	34	21	5
25-25	22	17	32	23	6
50-50	23	16	34	23	4
100-100	20	16	34	24	7
	1 lb. boron per acre applied to the soil				
0	22	14	33	24	7
10-10	21	13	31	28	7
25-25	22	15	34	23	6
50-50	21	16	36	23	4
100-100	23	18	35	21	3
	2 lbs. boron per acre applied to the soil				
0	22	14	35	25	4
10-10	22	14	34	24	6
25-25	22	16	35	24	3
50-50	24	17	35	21	3
100-100	22	15	35	22	6

Table 12. Effects of Boron Applications on the Dry Weight of Snap Beans, Aurora.

Grams per Five-Plant Sample				
Foliar Rates	Soil Rates of Boron Per Acre			
ppm B	0	1 lb.	2 lbs.	Means
0-0	54.3	57.8	65.0	59.0
10-10	49.5	64.2	64.5	59.4
25-25	55.3	60.4	61.8	59.2
50-50	61.8	60.3	61.4	61.6
100-100	56.4	61.4	55.5	57.8
Means	55.6	60.8	61.6	

Dry Weight: The data on the dry weight of snap beans are presented in Table 12. Addition of one and two pounds boron per acre to the soil resulted in an over-all increase in the dry weights of bean plants. The means for the zero, one, and two pounds per acre boron levels were 55.6, 60.8, and 61.6 grams, respectively. The increase in the dry weight of plants resulting from the addition of boron to the soil was of the magnitude of 9.3 percent for the one pound boron treatment and 11.4 percent for the two pounds treatment above the dry weight recorded for the zero boron treatment.

Mean dry weights of the five foliar rates of boron were increased up to the rate of 50-50 ppm and then were decreased at the 100-100 ppm rate. At the zero and one pound rates of boron applied to the soil, the pattern of increase was not consistent with increasing foliar boron levels. At the two pounds per acre soil boron application, foliar applications of boron decreased dry weights of plants.

Highest dry weights were obtained from plants grown on soil to which two pounds of boron per acre had been added and which received no foliar application.

Boron applications to the soil or in spray form to the plants did not have any statistically significant effect on dry weights of bush beans as shown by analysis of variance data in Appendix Table 1.

Boron Content: Results obtained from boron determinations of the early sample are presented in Table 13. Although these data were not statistically analyzed, it can be seen that boron levels of the plants, in general, were increased by soil and foliarly applied boron. However, while increasing the soil boron levels always resulted in an increase in boron content in the plant, increasing the foliar rates of boron did not always show a similar trend. In some cases the latter resulted in a decrease in boron content, and in general, foliar applications showed a somewhat erratic pattern in affecting the internal boron level of the plants.

Table 13. Effects of Boron Applications on Boron Content of Bush Beans, Aurora. (Early Sampling)

Boron Content in ppm B

Foliar Rates ppm B	Soil Rates of Boron Per Acre 0	1 lb.	2 lbs.	Means
0-0	33.1	41.2	42.7	41.0
10-10	34.3	42.3	50.8	42.5
25-25	37.8	37.5	45.6	40.3
50-50	35.2	32.8	45.7	37.9
100-100	44.7	43.5	42.7	43.6
Means	37.0	39.5	45.5	

Statistical analysis data on boron content of bush beans of the major sampling presented in Appendix Table 8, show that boron content of plants was significantly increased by both soil and foliar applications of boron, and that these increases were significant at the 1 percent level. This analysis is based on the second sampling; the plants had received their complete foliar treatments and were in bloom.

Data on boron content of bean plants as influenced by boron applications, are presented in Table 14. When means are compared, the application of one and two pounds boron per acre to the soil significantly increased the boron content of plants over that of plants receiving no boron. There was no significant difference in boron levels in plants grown at the one and two pound rates of soil applied boron.

Data on the effects of foliar boron applications on the boron content of bush beans indicate boron sprays significantly increased boron content of plants above that of the check treatment. Application of boron to the foliage of bean plants increased the boron content of plants grown on the zero soil boron level to a greater extent than boron content of plants grown at the one and two pounds per acre soil boron rates. At the 100-100 ppm boron foliar level, the boron content of plants was approximately the same, regardless of soil rates of boron.

Table 14. Effects of Boron Applications on the Boron Content of Bush Bean Plants, Aurora.

Boron Content in ppm B

Foliar Rates ppm B	Soil Rates of Boron Per Acre 0	1 lb.	2 lbs.	Means
0-0	19.1	24.2	25.1	22.8
10-10	24.5	25.6	27.8	26.0
25-25	25.4	27.5	25.9	26.2
50-50	29.4	32.3	28.3	29.9
100-100	34.0	33.8	34.3	34.0
Means	26.5	28.7	28.3	

L.S.D.	Soil Means	Foliar Means
	.05 = 1.2	.05 = 1.6
	.01 = 1.7	.01 = 2.2

DISCUSSION

Effects of Boron Applications on Yield and Grades of Snap Beans

The boron rates which were applied to the soils used in these experiments did not significantly affect yield of bush beans. In the Corvallis experiment, plants grown with a rate of one pound boron per acre produced approximately the same yields as did plants which were grown with no boron applied to the soil. The application of two pounds of boron per acre to the soil slightly decreased the yield, but the decrease was not statistically significant. Similar results were obtained at Aurora, except that plants grown at rates of one and two pounds boron per acre yielded slightly less than plants grown where no boron was applied to the soil.

The boron rates applied to the soil in these experiments apparently were within the range of tolerance to boron by beans. Except for a few bean seedlings which showed slight boron toxicity symptoms early, no further toxicity symptoms from soil-applied boron were observed during the experimental period. Laboratory analysis of the two soils used showed that the mean boron levels for the zero, one, and two pounds boron per acre rates were 1.25, 1.50, and 2.16 ppm boron, respectively, for the Chehalis soil at Corvallis and 0.89, 1.16, and 1.17 ppm boron for the Willamette soil at Aurora. Statistical analysis of these data showed that difference in means of these soil levels were significant at Corvallis but not at Aurora (Appendix Table 9).

An earlier soil sampling, prior to planting at Aurora, indicated boron content of the soil to be 0.4 ppm boron. Because of this low boron content this soil was chosen for the experimental site. However, a month later, after the application of boron materials to the appropriate plots, soil analysis indicated a boron content of 0.89 ppm for plots receiving no boron. While a small departure from the first reading would have been considered normal, the magnitude of this departure was so great as to invite speculation as to why such an increase should have taken place.

Previous analysis of this soil showed that its boron content was in the range of 0.4 to 0.5 ppm boron. The major sampling (second sample) was collected one or two days after an irrigation. Although it is assumed that this would not basically affect the boron content of this soil, there exists the possibility of contamination from the paper bags in which the soil samples were collected. Winsor (54, Vol. 34, p. 389-394) reported that wet soil samples are subject to boron contaminations if collected in paper bags. Therefore, there is a strong possibility that this sharp increase in boron content in this soil was due to such contamination.

Earlier work under greenhouse conditions in Oregon by Jordan and Powers (28, Vol. 11, p. 324-331), using the Bountiful bean as indicator plant for medium texture soils, showed boron levels below 0.50 ppm boron to be deficient, levels of 0.50 to 0.75 ppm as optimum, and boron levels above these as toxic. Jordan (27, p. 1-61) reported that Bountiful beans grown in a Melbourne silty clay loam with an available boron content of 1.10 ppm exhibited marked symptoms of boron toxicity. However, no symptoms of toxicity were observed on plants grown on a Klamath peat containing 2.50 ppm boron. Results obtained in this experiment would suggest that bean plants have a wider range of tolerance toward boron levels than previously reported. However, it should be remembered that due to the possibility of contamination, soil boron levels in this study may be 60 to 100 percent higher than their true values.

Jordan (27, p. 1-61) reported obtaining a crop of bean plants from a soil containing 50 ppm boron. At the same time this author reported observing boron toxicity symptoms on bean plants grown in a soil having a boron level of 1.10 ppm. These results appear to be in conflict with findings by other investigators. Wester and Magruder (36, Vol. 38, p. 472-474) obtained a statistically significant increase in yield of bush beans by side dress application of borax at rates of 10 to 15 pounds per acre. Untreated plants showed no boron deficiency symptoms during the experimental period; this would suggest that bean plants when grown on soils with a low-boron content may respond to boron fertilization even when no symptoms of deficiency are apparent.

It should also be emphasized, however, that the method used for applying boron is important. Brown (39, p. 1-13) reported that bean plants could easily by injured by low rates of applications of borax placed close to the seed. However, broadcast applications of as high as 20 pounds of borax per acre injured bean plants only slightly.

All the foliar rates of boron applied at Corvallis, except the 500 ppm boron rate, slightly increased yield above the yield produced by the treatment receiving no foliar application of boron. At Aurora, yield followed an erratic pattern, for no consistent response could be observed as a result of foliar applications of boron. Plots receiving no foliar treatment of boron produced 4.64 tons per acre, and all the foliar treatments, except the 50-50 ppm B treatment, produced lower yields than those receiving no boron. Differences in yield due to foliar applications of boron were not statistically significant.

The boron levels used in this study had no distinct influence on the number of flowers or percent pod set of snap beans. At Corvallis the mean percent pod set for plants grown at the zero, one, and two pounds boron rates were 22.7, 20.8, and 23.4, respectively. (Appendix Table 5)

Since foliar rates of boron above 250 ppm produced toxicity symptoms on snap bean plants, it is of interest to observe what effects, if any, the application of these foliar rates of boron had on percent pod set of snap beans. The data indicate that plants receiving the higher foliar rates of boron generally had as high or a higher percent pod set than those which did not receive boron foliarly. Although, in general, pod set was stimulated slightly by boron applications, no significant yield increase was produced.

Early work by Warrington (48, Vol. 40, p. 27-42) showed that boron is essential for completion of the life cycle of the bean and that in the absence of boron the plant fails to set pods. Below a certain level of boron, deficiency would be expected, and above it, luxury consumption of this element by the bean plant would take place. This has been shown to be the case for other plant nutrients such as nitrogen and potassium. Critical levels of boron above or below which snap beans fail to set and develop pods have not been reported.

On the basis of these results, it appears that all foliar rates of boron applied, with the possible exception of the 500 and 1,000 ppm boron rates, were within a range of boron tolerance of snap beans. The data show that plants receiving the foliar applications of 250 ppm boron produced a yield equal to that produced by the non-boron treated plants.

Effects of more concentrated foliar sprays on bean plants were observed at Corvallis. Concentrations as high as 2,000 ppm of boron were applied foliarly to bean plants the day before the early treatment was applied to the plants in the major plot area. It was observed that rates of 2,000 ppm boron, when applied in a single application, caused partial defoliation and stunting of the bean plants. Even though the plants remained smaller than those which did not receive boron treatments, they developed new leaves and produced a comparatively good set of pods. The application of 1,000 ppm boron at this time also produced some defoliation and stunting of the plants, but the toxicity was not as severe as in the 2,000 ppm boron plants, and plants recovered foliage much faster.

Data on the effects of time of application of foliar boron on yield show that the early treatment decreased yields below that produced by the check treatment by two and one-half percent. There was only a slight difference between the yields produced by the late and early-late treatments. However, plants receiving foliar boron at the late treatment produced the highest yields of all three treatments. The differences in yield due to time of application were not statistically significant.

It is interesting to observe that the split application in the form of 500-500 ppm during the early-late treatment, although equal in total boron content to the 1,000 ppm boron application, did not cause defoliation or stunting. These observations seem to indicate that plants can better tolerate high foliar levels of boron when these are applied over an extended period of time than when these amounts are applied in a single application.

Sieve size grades of bush beans were not affected by boron applications, so there was no apparent effect on maturity. This perhaps could be expected since applications of boron did not produce significant reduction in total yield of beans.

Effects of Boron Applications on Dry Weights of Bean Plants

At Corvallis, applications of boron generally resulted in a decrease in the dry weights of bean plants. At Aurora, similar applications resulted in an increase in the dry weights of plants, yet analysis of variance showed that these differences were not statistically significant. Average dry weight of plants sampled at bloom at Corvallis were higher than dry weights of plants at Aurora. However, plant population per foot of row was higher at Aurora than at Corvallis. The planting date for beans at Corvallis was approximately six weeks earlier than at Aurora so that plants at Aurora developed under higher average temperature conditions than those at Corvallis.

The fact that boron levels in the soil were lower at the Aurora site than at Corvallis could, at least in part, account for the discrepancy in trends of dry weight production due to boron applications. The factors mentioned earlier may have also contributed to the difference in response trends from boron applications. Although, in some cases, there appeared to be a relationship between dry weights and yield, this association was neither always marked nor consistent in regard to response from boron applications.

In classifying or determining soil levels of boron to which beans would respond differentially, Jordan and Powers (64, Vol. 11, p. 324-331) grew plants to the flowering stage and measured green and dry weights. Under field conditions, would a classification of deficient, optimum, and detrimental or toxic levels of boron in the soil be the same for dry weight production for plants as for yield of pods?

Wester and Magruder (36, Vol. 38, p. 472-474) in experimental work with lima beans found that applications of borax did not affect the weight of plants. Lingle and Carolus (61, Vol. p. 507-515) reported that dry weight of snap beans was depressed 11 percent by side dress application of ten pounds borax per acre and 22 percent by 20 pounds borax per acre. Callings (54, Vol. p. 83-105) found that applications of 2.50 mgm of boron per liter of nutrient solution increased the dry weights of soybean plants.

<u>Effects of Boron Applications on Boron Content of Bean Plants</u>

An increase in boron content of plants was observed as a result of boron applications to the soil. The increases of boron content in plants were statistically significant and seem to be in agreement with the literature which states the existence of a positive relation between soil boron content and boron levels within the plant. Lingle and Carolus (29, Vol. 71, p. 507-515) found 48.9 ppm boron, on a dry weight basis, in the foliage of snap beans in Michigan. In all probability this was a supra-optimal level inasmuch as further applications of borax fertilizer depressed yield. However, these authors did not state at what age the plants were sampled; neither did they report the boron status of the soil. Brown (8, p. 1-13), Mack (30, Vol. 51, p. 147-148) and others reported that on the average, the boron content of bean plants at bloom which appeared to be adequately supplied with boron, was about 25 to 30 ppm boron.

Lingle and Carolus (61, Vol. 71, p. 507-515) applied 20 pounds borax per acre to a Michigan soil and reported that bean plants grown on this soil contained 160.6 ppm boron, on a dry weight basis. Mack (30, Vol. 51, p. 147-148) found bean plants grown on a Chehalis soil averaging 4.18 ppm B contained 206 ppm boron.

Laboratory analysis records show the plants from the first sample had a higher boron content than did plants of the main sampling. This indicates that time of sampling is important and should be taken into consideration whenever boron content of plants is reported. However, it would appear that the differences in boron content between the early and main sampling could be attributed in part to the fact that the plants of the main sampling, were larger, and therefore their early boron concentration could have been diluted by increase in size of the plants.

Effects of foliar applications of boron on the boron content of bean plants were also statistically significant. (Appendix Tables 4 and 8) Although the increase of boron content in plants as a result of foliar applications of boron was statistically significant, the plants did not absorb boron in proportion to the rates applied. Boron content of plants at bloom ranged from approximately 22 to 50 ppm at Corvallis and 20 to 35 ppm at Aurora. The data indicate that plants receiving the highest foliar rates of boron contained approximately twice as much boron as did those receiving no foliar boron, However, this increase was not proportional to the concentration applied. This would suggest that plants may exercise selectivity and may tend to absorb lesser amounts of boron as their boron content increases.

The plots were sprinkler irrigated three days after each foliar treatment. Therefore, it may have been that part of the boron applied still remained on the leaves instead of being absorbed and was washed off the foliage by the irrigation water. It is somewhat surprising, however, that high rates of foliar applied boron produced no higher levels than approximately 50 to 70 ppm boron in the bean plants in this study. Limited observations indicated that plants contained a higher content of boron from a given foliar application under greenhouse conditions than under field conditions.

SUMMARY

The effects of soil and foliar applications of boron on growth, yield and boron content of bush snap beans were studied in field plots at Corvallis and Aurora. Three rates of soil applied boron, zero, one, and two pounds boron per acre, as well as foliar-applied boron at rates up to 1000 ppm B, were included.

Soil and foliar applications of boron had no statistically significant effect on yield of snap beans. Neither grades of pods nor percentage pod set appeared to be affected by boron treatments. There was a trend of decreasing yield as soil boron rates were increased with the magnitude of this decrease being less than two and one-half percent when compared to check treatments receiving no boron applied to the soil. The response in yield due to foliar-applied boron was erratic; in some cases small increases on yield were obtained from lower rates of boron but decreases in yield were obtained at rates of 500 ppm B and higher. At Corvallis where time of application of foliar sprays of boron were evaluated, plants receiving a foliar spray of boron prior to bloom produced a smaller yield than either plants receiving foliar boron at bloom or those receiving a combination treatment equivalent in boron concentration. These differences in yield were not significant, however.

Average dry weights of plants were decreased as rates of boron to the soil were increased at Corvallis. At Aurora, there

was a small increase in dry weight production from soil-applied boron. As was the case in yield data, no consistent trends in dry weights of plants were evident because of foliar applications of boron.

Boron content of plants was significantly increased because of soil and foliar applications of boron. Boron content of plants at bloom ranged from approximately 22 to 50 ppm at Corvallis and 20 to 35 ppm at Aurora. Plants receiving the highest rates of foliar boron contained almost twice as much boron as those which received no foliar boron. Plants sampled prior to bloom had higher boron levels than plants sampled at bloom, indicating that the boron level in plants is related to time of sampling.

Under the experimental conditions present in this study, neither the soil nor the foliar boron treatments exerted any significant beneficial or detrimental effects on growth and yield of bush snap beans.

BIBLIOGRAPHY

1. Agulhon, H. The use of boron as catalytic fertilizer. Comptes rendus des Seances de l'Academie des Sciences 150: 288-291.

2. Alexander, Taylor R. Anatomical and physiological responses of squash to various levels of boron supply. Botanical Gazette 103: 475-491. 1941.

3. Batjer, L. P. and A. H. Thompson. Effect of boric acid sprays applied during bloom upon the set of pear fruits. Proceedings of the American Society for Horticultural Science 54: 141-142. 1949.

4. Berger, K. C. and E. Truog. Boron determination in soil and plants, using the quinalizarim reaction. Industrial and Engineering Chemistry 11: 540-554. 1939.

5. Boas, F. Durroschadon und ihre Bokampfung. Deutsche Landwirtschaftliche Presse 1: 393. 1934.

6. Brandenburg, E. The heart and dry rot of beets as a sign of boron deficiency. Phytopathologische Zeritschrift 3: 499-517. 1931.

7. Brenchley, Winifred and H. A. Thornton. The relation between the development, structure, and functioning of the nodules on *Vicia faba*, as influenced by the presence or absence of boron in the nutrient medium. Proceedings of the Royal Society, Ser. B., 98: 373-379. 1925.

8. Brown, B. A. Boron research at the Storrs Agricultural Experimental Station. Storrs, 1953. 13 p. (Connecticut. Agricultural Experiment Station Information No. 47).

9. Burrell, A. B. Boron in apple leaves and fruits as influenced by sodium pentaborate sprays. Proceedings of the American Society for Horticultural Science 71: 20-25. 1950.

10. Callings, G. H. The influence of boron in soybean. Soil Science 23: 83-105. 1927.

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

12. Dennis, R. W. G. The relation of boron to plant growth. Science Progress 32: 58-69. 1937.

13. Dennis, A. C. and R. W. G. Dennis. Boron and plant life. Part III. Developments in agriculture and horticulture. Fertilizer, Feeding Stuffs and Farm Supplies Journal. Feb. 8 and 22, Mar. 8 and 22, and April 5 and 19. 1939.

14. Dible, W. T., E. Truog, and C. C. Berger. Boron determination in soils and plants by the simplified curcumin procedures. Analytical Chemistry 26: 418-421. 1954.

15. Eaton, Frank M. Deficiency, toxicity, and accumulation of boron in plants. Journal of Agricultural Research 69: 237-277. 1944.

16. Eaton, S. V. Effects of boron deficiency and excess on plants. Plant Physiology 15: 95-107. 1940.

17. Grizzard, A. L. and E. M. Mathews. The effect of boron on seed production of alfalfa. Journal of the American Society of Agronomy. 34: 365-368. 1942.

18. Hatcher, J. T., G. Y. Blair, and C. A. Bower. Response of beans to dissolved and adsorbed boron. Soil Science 88: 98-100. 1959.

19. Hernandez, E. M. and John Shive. Calcium-boron relationships in the nutrition of corn and the distribution of these elements in the plant. The Journal of Agriculture of the University of Puerto Rico 30: 253-291. 1946.

20. Hoagland, D. R. and W. C. Snyder. Nutrition of strawberry under controlled conditions. Effects of deficiencies of boron and certain other elements. Proceedings of the American Society for Horticultural Science 30: 288-294. 1933.

21. Hussin, M. H. Effects of mineral nutrition on the development of crown gall caused by Agrobacterium tumefaciens. Ph.D. Thesis. Corvallis, Oregon State University, 1962. 106 numb. leaves.

22. Hutcheson, T. B. and R. P. Cocke. Effects of boron application on yield and duration of alfalfa. Virginia, 1942. (Virginia Experiment Station Bulletin 336).

23. Huyskes, J. A. The significance of boron in bean cultivation. Tijdschrift over plantenziekten 46: 133-139. 1940.

24. Johnson, E. S. and W. H. Dore. Relation of boron to growth of the tomato plant. Science 67: 324-325. 1928.

25. Johnston, Earl S. and Paul L. Fisher. The essential nature of boron to the growth and fruiting of the tomato. Plant Physiology 5: 387-392. 1930.

26. Jones, Harold E. and John D. Scarseth. The calcium-boron balance in plants as related to boron needs. Soil Science 57: 15-24. 1944.

27. Jordan, V. J. Optimum and critical concentrations of boron in Oregon soils. Ph.D. Thesis, Corvallis, Oregon State College. 1947. 75 numb. leaves.

28. Jordan, J. V. and V. L. Powers. Status of boron in Oregon soils and plant nutrition. Soil Science Society of America Proceedings 11: 324-331. 1947.

29. Lingle, J. C. and R. L. Carolus. Sodium and boron contents of several vegetable crops and varieties as influenced by the sodium and boron levels of the soil. Proceedings of the American Society for Horticultural Science 71: 507-515. 1958.

30. Mack, H. J. Boron residual studies on vegetable crops. Proceedings of the Oregon State Horticultural Society 51: 147-148. 1959.

31. McMurtrey, J. E., Jr. The effect of boron deficiency on the growth of tobacco plants in aerated and unaerated solutions. Journal of Agricultural Research 38: 371-380. 1929.

32. Monk, R. Movement of heavy applications of borax through the soil. New Zealand Journal of Science and Technology. A. Agricultural Research Sect. 35: 22-32. 1953.

33. Morse, W. J. Some observations upon the effects of borax in fertilizers. Orono, 1920. 120 p. (Maine Agricultural Expt. Station Bulletin No. 288).

34. Muhr, R. Gilbert. Plant symptoms of boron deficiency and the effects of borax on the yield and chemical composition of several crops. Soil Science 54: 55-65. 1941.

35. Naftel, James A. Recent studies on boron in soils. American Fertilizer 89: 1-26. 1938.

36. Nebergall, William H. and Frederic C. Schmidt. Textbook of general chemistry. Boston, D. C. Heath. 1959. 724 p.

37. Neller, J. R. and W. J. Morse. Effects upon the growth of potatoes, corn and beans resulting from the addition of borax to the fertilizer used. Soil Science 12: 79-105. 1921.

38. Owen, E. C. The effects of borax dressings on the growth and yield of field beans, Vicia faba. Journal of Agricultural Science 35: 119-122. 1945.

39. Page, N. P. and W. R. Paden. The relation between differential response of snap beans, crimson clover, and turnips to varying rates of calcium and sodium borates on three soil types. Soil Science Society of America. Proceedings 14: 253-259. 1950.

40. Peland, J. R., C. F. Ireland, and H. M. Reisenauer. The importance of borax in legume seed production in the South. Soil Science 57: 75-84. 1944.

41. Powers, W. L. Boron in relation to soil fertility in the Pacific Northwest. Soil Science Society of America. Proceedings 4: 316-321. 1939.

42. Purvis, E. R. The present status of boron in American Agriculture. Soil Science Society of America. Proceedings 4: 316-321. 1939.

43. Purvis, E. R. and W. J. Hanna. Vegetable crops affected by boron deficiency in eastern Virginia. Blacksburg, 1940. 23 p. (Virginia Experiment Station Bulletin No. 105).

44. Rogers, B. L. "Blossom blast", and incipient boron deficiency. Proceedings of the American Society for Horticultural Science 62: 119-122. 1953.

45. Schmucker, T. The influence of boric acid on plants, especially on germinating pollen grains. Planta 23: 264-268. 1935.

46. Schuster, C. E. Plant responses to soil characteristics. Proceedings of the Oregon State Horticultural Society 28: 63-68. 1937.

47. Warrington, Katherine. The effects of boric acid and borax on the broad bean and certain other plants. Annals of Botany 37: 629-672. 1923.

48. Warrington, Katherine. The changes induced in the anatomical structure of Vicia faba by the absence of boron from the nutrient solution. Annals of Botany 40: 27-42. 1926.

49. Wear, John I. Boron requirements for crimson clover seed production, its accumulation in soils and residual effects on sensitive crops. Agronomy Journal 48: 132-134. 1956.

50. Wear, J. I. Boron requirements of crops in Alabama. Auburn, 1957. 32 p. (Alabama Agricultural Experiment Station Bulletin No. 305).

51. Western, Robert E. and Roy Magruder. Effect of boron on plant growth and dry seed yield of lima bean - Phaseolus lunatus. Proceedings of the American Society for Horticultural Science 38: 472-474. 1941.

52. White-Stevens, R. H. Limits in the use of borax in the production of certain vegetable crops. Proceedings of the American Society for Horticultural Science 39: 367. 1941.

53. Wilson, M. Clarence, Roy L. Lovvorn, and W. W. Woodhouse, Jr. Movement and accumulation of water-soluble boron within the profile. Agronomy Journal 43: 363-367. 1951.

54. Winsor, H. W. Boron contamination of soil samples collected in paper bags. Soil Science 84: 389-394. 1957.

55. Yamaguchi M. and P. A. Minges. Brown checking of celery, a symptom of boron deficiency. Part I. Field observations, variety susceptibility, and chemical analyses. Proceedings of the American Society for Horticultural Science 68: 318-323. 1956.

APPENDIX

Appendix Table 1. Analysis of Variance on the Effects of Boron Applications on Yield of Bush Beans, Corvallis.

Source of Variation	D.F.	S.S.	Mean Squares	F
Soil Levels	2	4.08	2.040	-----
Foliar Applications	14	40.44	2.888	1.045
Foliar Soil	28	76.0C	2.714	-----
Replication	3	66.15	22.050	7.983
Error	132	364.66	2.762	-----
Total	179	551.33		

Appendix Table 2. Analysis of Variance on the Effects of Application of Two Pounds Boron per Acre to the Soil on Yield of Bush Beans, Corvallis.

Source of Variation	D.F.	S.S.	Mean Squares	F
Treatments	14	83.10	5.935	2.050*
Replications	3	29.42	9.806	3.387**
Error	42	28.95		
Total	59	234.15		

* Significant at 5 percent level.

** Significant at 1 percent level.

Appendix Table 3. Analysis of Variance on the Effects of Boron Applications on Dry Weights of Bush Beans, Corvallis.

Sources of Variation	S.S.	D.F.	M.S.	F
Foliar Treatment	2975.44	14	212.53	0.417
Soil Level	2893.51	2	1446.75	2.841
Foliar Treatments	10592.33	28	378.29	0.743
Replication	7732.46	3	2577.48	5.062
Error	67205.04	132	509.12	
Total	91398.78	179		

Appendix Table 4. Analysis of Variance on the Effects of Boron Applications on Boron Content of Bush Bean Plants, Corvallis.

Source of Variation	D.F.	S.S.	M.S.	F
Soil Level	2	287.86	143.930	9.182**
Foliar Application	14	12870.56	919.325	58.652**
Foliar & Soil	28	756.78	27.027	1.724*
Replication	3	129.64	43.213	2.756*
Error	132	2068.98	15.674	
Total	179	16113.82		

* Significant at 5 percent level.
** Significant at 1 percent level.

Appendix Table 5. Effects of Boron Applications on Percent Pod Set of Bush Beans, Corvallis.

Foliar Rates	Soil Boron Levels 0	1 lb.	2 lbs.	Means of Foliar Rates
ppm B				
		Early Treatment		
0	24.2	18.2	19.8	20.6
10	23.7	24.9	20.3	23.0
50	21.1	23.6	23.6	22.7
100	26.4	19.5	25.5	23.8
500	20.7	22.3	24.4	22.4
Means	23.2	21.7	22.7	23.-
		Late Treatment		
10	20.6	18.3	22.1	20.3
50	24.4	20.2	21.5	22.0
100	25.2	21.2	28.8	25.1
500	25.1	19.1	20.1	21.4
Means	23.6	19.7	23.1	22.2
		Early-Late Treatment		
10	22.7	21.2	26.2	23.4
50	18.9	21.2	24.8	21.6
100	20.5	19.2	23.5	21.1
500	20.4	22.2	23.3	22.0
Means	20.6	20.9	24.4	22.0
Soil Means	22.7	20.8	23.4	

Appendix Table 6. Analysis of Variance on the Effects of Boron Applications on Yield of Bush Beans, Aurora.

Source of Variation	D.F.	S.S.	M.S.	F
Replication	3	0.391	0.130	-----
Treatment	14	1.699	0.121	-----
Soil Level	2	0.192	0.096	-----
Foliar Treatment	4	1.158	0.289	1.545 ns
Soil x Foliar	8	0.349	0.043	-----
Error	42	7.869	0.187	
Total	59	9.959		

Appendix Table 7. Analysis of Variance on the Effects of Boron Applications on Dry Weights of Bush Bean Plants, Aurora.

Source of Variation	D.F.	S.S.	M.S.	F
Soil Level	2	453.26	226.63	2.293
Foliar	4	72.19	18.04	0.182
Foliar x Soil	8	583.03	72.87	0.737
Replications	3	970.21	323.40	3.272
Error	42	4150.26	98.81	
Total	59	6229.05		

Appendix Table 8. Analysis of Variance on the Effects of Boron Applications on Boron Content of Bush Beans, Aurora.

Source of Variation	D.F.	S.S.	M.S.	F
Soil Level	2	53.29	26.69	6.865**
Foliar Treatment	4	888.24	222.06	57.231**
Foliar x Soil	8	95.04	11.88	3.061**
Replication	3	13.14	4.38	1.128
Error	42	163.29	3.88	
Total	59	1213.06		

** Significant at 1% level of probability.

Appendix Table 9. Analysis of Variance on Effects of Boron Applications to the Soil on Soil Levels of Boron.

Location	Source of Variation	D.F.	S.S.	M.S.	F
Corvallis	Reps	3	0.0326	0.0109	-----
	Treatments	2	1.7602	0.8801	12.25**
	Error	6	0.4311	0.0719	
	Total	11	2.2239		
Aurora	Reps	3	0.0554	0.0185	-----
	Treatments	2	0.2036	0.1018	4.55
	Error	6	0.1342	0.0224	
	Total	11	0.3932		

** Significant at the 1% level of probability.