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Title: Effect of Boron on Seven Vegetable Crops Grown on Two Soil Types

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Boron deficiency or toxicity can reduce yield and quality of vegetables. Seven vegetable crops, varying from low to high boron requirements were grown in field plots at Corvallis in 1987. Leaf-B and yield components of green bean, cucumber, potato, carrot, tomato, broccoli and table beet were examined under conditions of fall or spring soil applied B at a 5 kg/ha rate on two soil types. Soil tests on control plots indicated B levels of .39 mg/kg and .20 mg/kg in the top 23 cm of soil in the silty clay loam and sandy loam soil, respectively. Fall or spring application of B increased soil B levels in the top 23 cm on the silty clay loam soil to .68 mg/kg and .37 mg/kg, and on the sandy loam soil to .81 mg/kg and .42 mg/kg, respectively.

Boron application had no effect on yield or yield components except in green beans where spring applied B on the sandy loam reduced percent of premium grade pods (sieve sizes 1-4). Leaf-B levels were not affected in cucumber, carrot, or tomato on either soil. Boron application on

both soils had a significant effect on leaf-B levels in bean, broccoli and table beet. Potato leaf-B was significantly affected only on the sandy loam soil.

Effect of Boron on Seven Vegetable Crops
Grown on Two Soil Types

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INTRODUCTION

Boron is the most widely deficient micronutrient in many soils and geographic regions of the United States (Mengel 1982, Sparr 1970). Boron deficiency has been implicated in reducing yield, quality and marketability in many crops. In the acidic, highly leached soils of western Oregon, boron deficiency is common and boron applications are frequently used on some of the processing vegetables, table beets, carrots, broccoli, cabbage and cauliflower, grown in the Willamette Valley. Boron toxicity from soil residual boron can affect yield and quality of subsequent boron sensitive crops but generally has not been a problem in western Oregon. There is a need for studies to be conducted where response of several vegetable crops to boron can be evaluated in the same location at the same time under similar environmental conditions.

Therefore, this project was undertaken to determine the effects of fall or spring applications of 5 kg B/ha on seven vegetable crops with varying degrees of boron sensitivity or requirements. Two soils of different textural classes were used to measure their effect on crop response to boron applications.

LITERATURE REVIEW

I. Role and Availability of Boron

Boron (B) is classified as an essential micronutrient, required by vascular plants for optimum growth and for completion of the lifecycle. Although the exact role of boron in plant nutrition is not well understood, it is essential in many physiological processes. Boron is involved in nucleic acid metabolism, carbohydrate biosynthesis, synthesis of plant hormones, cell division and elongation, and membrane function and structure (Mengel 1982, Marschner 1986, Gupta 1979, and Pilbeam and Kirkby 1983). Pollen production, viability, germination and pollen tube growth are also affected by boron supply (Mengel 1982, Marschner 1986).

In determining salt and boron tolerance of many crops and ornamental species, Maas (1986) devised a boron tolerance rating system based on soil water boron threshold levels that did not reduce yields. Maas' ratings and threshold levels are: very sensitive (<0.5 mg/kg), sensitive (0.5-1.0 mg/kg), moderately sensitive (1.0-2.0 mg/kg), moderately tolerant (2.0-4.0 mg/kg), tolerant (4.0-6.0mg/kg), and very tolerant (6.0-15.0 mg/kg). Many factors influence the relative boron deficiency or toxicity to a crop including soil type, irrigation practices, fertilizer application, solubility of boron fertilizers, climate and crop varieties (Page and Paden 1949).

Root uptake of boron from the soil solution is primarily a passive process associated with mass flow of water and transpiration rate. Translocation of B through the xylem is predicated by transpiration rate (Mengel 1982). Halbrooks, Peterson, and Kozlowski (1986) observed that the uptake of B by roots of table beets was directly related to the transpiration rate, but that xylem transport of B was independent of transpiraton rate, but dependent on dry weight accumulation.

Boron is considered to be phloem immobile, but translocation of B from older leaves to developing sinks may occur under conditons of B starvation. In studies on rutabaga, radish and cauliflower, (Shelp and Shattuck 1987, Shelp, Shattuck and Proctor 1987) the authors found that redistribution of B from older leaves occurred under conditions of B deficiency. Hanson (1991) demonstrated B export from deciduous tree fruit leaves after foliar application of B.

Boron is the most widely deficient micronutrient, with deficiencies reported in 43 states (Sparr 1970). Boron is present in most soils at 20 - 200 mg/kg, most of which is unavailable to plants (Mengel 1982, Tisdale and Nelson 1975). According to Gupta (1979) plant available boron, measured by hot water extraction, ranged from 0.38 - 4.67

mg/kg. In agricultural soils (pH <8) soil solution boron exists as boric acid (H_3BO_3). Boric acid is easily leached from the soil (Mengel 1982, Tisdale and Nelson 1975, Marschner 1986).

Boron is present in many minerals, of which tourmaline (3 - 4% B) is the most important (Berger 1949, Mengel 1982). Tourmaline is resistant to weathering, so replenishment of soil B from this mineral may not supply adequate B to cropping systems with heavy boron demand (Berger 1949, Tisdale and Nelson 1975).

Other factors that affect boron availability are soil organic matter, soil texture, soil pH, and soil moisture. Most of the available boron in acid soils is held by the organic matter (Mengel 1982, Tisdale and Nelson 1975, Berger 1949) and is released by microbial activity (Gupta 1979). Parker and Gardner (1982) found that in three related sandy Newberg soils, the soil with the higher organic matter content (4%) retained more of the applied boron than the soils with 0.9% and 1.1% organic matter. Fine textured soils adsorb more boron than course textured soils. The amount and the type of clay mineral affect boron adsorption (Keren and Bingham 1985).

Soil pH and moisture influence boron availability. Boron uptake by plants exhibits a negative relationship above pH 6.5 (Keren and Bingham 1985). As the pH rises, the anion $B(OH_4)^-$ is formed and is adsorbed onto clay minerals. Repeated wetting and drying cycles increase the amount of boron fixed to clay particles. The degree of fixation is often greater in limed than in unlimed soils (Berger 1949, Keren and Bingham 1985).

Soil moisture alters the availability of boron. In very wet, acidic, highly leached conditions, boron deficiencies may occur. Under drought conditions, boron fixation may increse, and organic matter decomposition may slow, thereby reducing plant available boron in the surface soil. Hobbs and Bertramson (1949) illustrated this drought reduction in available B using a split root system on tomatoes. Half of the root system was placed in a dry topsoil that contained adequate boron, the other half in a moist subsoil with very low levels of boron. As long as the top soil remained dry, the plants did not obtain adequate boron from the subsoil. In dry conditions, reduced boron availability and delivery, and low boron levels in the moist subsurface horizons can create plant of boron deficiency in soils that contain adequate levels of extractable boron.

II. Boron in Vegetable Production

Boron nutrition is vital for obtaining high quality yields in vegetables. Though total yield may not be affected, adequate quality for processing or fresh marketing of vegetables may not be obtained if available soil boron is inadequate (Mack 1959). Heart rot of sugar beet, black heart in turnips, cracked stem in celery, brown rot in cauliflower and canker in red beets have all been characterized as diseases or disorders that are now known to result from boron deficiency (Atwater 1941).

Boron has a narrow concentration range between deficiency and toxicity. Boron deficiency is first expressed as abnormal or retarded growth in the apical tissues. If the deficiency persists, the terminal growing point dies, growth is reduced and the plant will take on a bushy, rosetted appearance. Young leaves are misshapen and internodes are shortened. Boron toxicity is expressed in leaves as marginal and tip chlorosis with subsequent necrosis (Mengel 1982, Marschner 1986, Gupta 1979, Maynard 1979). Boron toxicity is generally due to high concentrations of boron in the water supply, use of municipal compost high in boron, or misapplication of boron-containing fertilizers (Eaton 1944, Gupta 1979, Purves and Mackenzie 1974, Maynard 1979).

Vegetable species and even strains differ widely in their requirements for, and their tolerance to boron. Eaton (1944) grew 50 species of plants in sand culture and rated them as boron sensitive, semi-tolerant, and tolerant. His ratings were based on estimates of leaf injury as few crops were grown to maturity. Recent studies by Francois (1984, 1986, 1988, 1991) indicated that Eaton's rankings may not be indicative of boron tolerance of a species when grown to horticultural maturity. Eaton reported the lowest boron concentration in soil solution for injury on tomato, radish, celery, lettuce, and onion to be 5, 10, 25, 1 and 1 mg/kg, respectively. All of these vegetables were rated as boron semi-tolerant. Francois found that tomato fruit weights were not significantly affected by up to 10 mg/kg boron in the soil solution. Radish leaf necrosis was not observed with boron solution concentrations of 16 mg/kg. In celery, Francois reported a yield decrease when boron concentration exceeded 10 mg/kg, but at no time did the plant leaves exhibit boron toxicity symptoms. 'Southport White Globe' onions showed no significant difference in yield components at B concentrations up to 5 mg/kg in soil water. Francois' findings for lettuce were similar to those of Eaton.

Beans (Phaseolus vulgaris L.) are considered to be a boron sensitive crop (Maas 1986, Keren and Bingham 1985, Eaton 1944). Gupta (1983) reported boron toxicity symptoms of reduced growth and marginal leaf burn that occurred at 2 and 4 mg/kg soil-added boron and tissue boron levels of 125 and 232 mg/kg, respectively. Boron deficiency symptoIs, yellowing of the tops, slow flowering and pod formation, occurred under conditions of 0 soil added boron and boron tissue levels less than 12 mg/kg. Teare (1974) reported deficiency symptoms in beans grown in solution culture as root and top dwarfing, a darkening of the leaves and spot necrosis of the oldest leaves. The bean roots exhibited stunting within three days of transplanting to the boron deficient nutrient solution. In other work, beans grown under boron deficiency develop thickened and brittle roots with necrotic tips (Odhnoff 1961).

The extensive use of boron fertilizers has led to concerns over residual soil boron and the effect on subsequent cropping of boron sensitive species. In studies by Mack (1959), bean yields and plant dry weights were not adveresly affected until available soil boron concentration exceeded 2.30 mg/kg from a fall application of 17.9 kg/ha. Spring applications of boron above 2.2 kg/ha decreased yields and reduced plant dry weights. These results agree with work by Gupta and Cutcliffe (1984) on applied and residual boron on beans. Application rates of up to 8.8 kg B/ha the year prior to planting beans did not have a detrimental effect on yield.

Cucumbers (Cucumis sativus) are considered moderately sensitive (Maas 1986) to semi-tolerant (Keren and Bingham 1985) to soil boron. Maas (1986) considered a threshold of 1.0-2.0 mg/kg boron as the maximum allowable concentration in soil water consistent with good yields. In work on cumcumbers in sand culture, visible boron toxicity symptoms did not occur until the nutrient solution exceeded 2 mg/kg boron. A 50% reduction in growth occurred at 6 mg/kg soil boron (El-Shiek et al 1971). Gupta (1979) listed tissue boron concentrations for cucumber as <20, 40-120 and >300 mg/kg as deficient, sufficient and toxic, respectively.

Gupta (1979) reported potatoes (Solanum tuberosum L.) have a narrow range of tissue concentration from deficient to toxic. B tissue levels of <15 mg/kg were deficient, 21-50 mg/kg sufficient, >50 mg/kg toxic. In work on a limed sphagnum peat soil in Canada, <12 mg/kg plant B, with a corresponding water soluble soil B value of 1.5 mg/kg was deficient and toxicity symptoms were not expressed until plant boron levels reached 180 mg/kg with a corresponding soil B content of 8.0 mg/kg (MacKay et. al. 1962). Maas (1986) identified potatoes as moderately sensitive with a yield reduction threshold value of 1.0-2.0 mg/kg B in soil solution. Boron deficiency in potato results in death of the meristematic tissue, the internodes are shortened and the leaves become thickened and cupped (Gupta 1979). Eaton (1944) noted slight marginal chlorosis at 1 mg/kg B with toxicity symptoms of leaf burn and necrosis increasing in severity up to 25 mg/kg B in the nutrient solution. Tubers exhibited some skin russetting in the 25 mg/kg treatment.

Carrots, (Daucus carota L.) are considered to be a boron semi-tolerant crop (Eaton 1944, Keren and Bingham 1985), moderately sensitive with a soil boron threshold of

1.0-2.0 mg/kg (Maas 1986), and as having a medium requirement for soil boron at 0.1-0.5 mg/kg (Berger 1949). Gupta (1979) defined carrot boron tissue concentrations as deficient, sufficient and toxic at <16, 32-104, and 175-307 mg/kg, respectively.

Kelly, Somers and Ellis (1952) conducted research on Red Cored Chantenay carrots grown in sand culture at 0, 0.1, 0.5, 2.0, and 5.0 mg/kg boron. Deficiency symptoms developed in the 0 boron treatment and were later alleviated to assure root development. Deficiency was expressed as deformation and size reduction in new leaves, bronzing and chlorosis of older leaves and poor root development. Roots were small with sharply pointed tips, a light-colored periderm and longitudinal cracking. Toxicity occurred in the 5.0 mg/kg treatment as marginal chlorosis and curling of the leaflets. Highest root yields were obtained at 2.0 mg/kg B in the nutrient solution.

Tomato (Lycopersicum esculentum L.) is considered a boron tolerant species with a boron soil water threshold level of 4.0-6.0 mg/kg (Maas 1986, Keren and Bingham 1985). Gupta (1979) listed boron tissue concentrations of <10, 30-75 and >200 mg/kg as deficient, sufficient and toxic, respectively. Others have found toxicity symptoms above 72 mg/kg leaf-B (Adugayi 1978). Vegetative symptoms of boron deficiency and toxicity are the same as previously discussed for other crops.

Tomato fruit disorders caused by boron deficiency include open locule, internal browning and stem-end russetting. Maynard (1959) attributed open locule and russetting to rupture of thin-walled collenchyma cells caused by boron deficiency. Cerda and Roorda van Eysinga (1981) found similar fruit deformations on tomatoes grown in a split root system with no added boron.

Francois' (1984) work on tomatoes indicated that the quality of marketable fruit was significantly affected by increasing soil B concentration. As soil water concentration increased above 4 mg/kg fruit, size decreased. Highest yield of marketable fruit occurred at or below the soil boron concentration at which leaf injury was first observed.

Boron deficiencies in broccoli (Brassica oleracea L. var. italica Plenck) result in reduced growth and water soaked areas inside the heads (Gupta 1979). Toxicity symptoms may not be expressed as marginal necrosis of leaves (Francois 1986), though a phytotoxic response similar to wilting has been observed at a boron rate of 8 kg B/ha applied in a band (Vigier and Cutcliffe 1984). Maas (1986) listed broccoli as moderately sensitive to soil available boron with a threshold value of 1.0-2.0 mg/kg. Other authors describe broccoli as having a high boron requirement (Lorenz and Maynard 1980). Deficiency and sufficiency boron tissue concentrations have been reported at 2-9 and 10-71 mg/kg, respectively. Gupta (1979) did not report a toxicity level. Yields may be adversly affected by boron in excess of 1.0 $mg/litre^{-1}$ in sand culture (Francois 1986).

Hollow stem in broccoli reduces the marketability of the harvested heads. It is commonly associated with row spacing and nitrogen fertilization and adequate boron nutrition will not alleviate the condition (Gupta and Cutcliffe 1973). However, a correct balance of leaf NO_3-N:B can reduce hollow stem to minimum levels. Increased nitrogen fertilization increased the incidence of hollow stem damage; high boron treatment had no effect. Minimum levels of hollow stem occurred when the leaf NO_3-N:B ratio was in the range of 215:1 (Vigier and Cutcliffe 1984).

Internal breakdown or canker of table beets (*Beta vulgaris* L.) is a serious problem on soils low in available boron. On the calcareous soils of New York (Lorenz 1942) and the acidic, highly leached soils of western Oregon, boron fertilizer is required to produce a high quality beet crop. Mack (1959, 1989) demonstrated that while total yield was not usually affected, the incidence of canker decreased as boron fertilizer rates increased. Additional work on western Oregon soils showed that while liming and increased nitrogen application increased total root yield, increased rates of both nitrogen and boron were required to decrease the incidence of canker (Hemphill, Weber, and Jackson 1982). Deficiency, sufficiency, and toxicity of boron tissue levels in sugar beets are <20, 31-200 and >800 mg/kg, respectively, according to Gupta (1979). Other work has indicated that deficiency may occur in table beets at leaf tissue concentrations of 32-40 mg B/kg. Boron deficient beet plants develop leaf browning, and the roots are rough, scabby and poorly colored. Roots also develop sunken areas that appear dark when roots are cut (Gupta and Cutcliffe 1985).

Research has shown that table beet cultivars differ in response to soil available boron and boron deficiency. Genetic studies have indicated that susceptibility to low boron is dominant and conditioned by a single gene, but modifying genes are indicated by the intermediate responses exhibited by some progeny of susceptible parents (Tehrani et al 1971). The Morse strain of the cultivar Detroit Dark Red is considered very sensitive to boron deficiency, while the Ferry's strain is significantly more tolerant of low soil boron levels. Kelly and Gabelman (1960) concluded that the genetic system controlling tolerance to low boron condition in beets is very complex.

Total B content of beet leaf tissue is not necessarily indicative of sufficiency and resistance to canker. One study indicated that the beet cultivar that ranked highest in severity of boron deficiency had 25.33 mg/kg B and

1.059% Ca, while the cultivar most resistant to boron deficiency had 29.90 mg/kg leaf B and 0.735% Ca. The authors concluded that high calcium levels in leaf tissue increased the severity of boron deficiency symptoms and that boron deficiiency symptoms were less severe in cultivars and strains that accumulated the greatest amounts of boron in leaf tissue (Kelly and Gabelman 1960).

MATERIALS AND METHODS

The plots for this study were established in two sites at the Oregon State University Vegetable Research Farm at Corvallis. The two soil types (textures) used in the study, as determined by the Oregon State University Soil Physics Laboratory, were classified as a silty clay loam and a sandy loam (Table 1).

Three B treatments consisted of control plots with no applied boron and fall or spring soil applications of 5 kg B/ha (Solubor 20.5% B). These main plots were arranged in a randomized complete block with four replications on each soil type. Seven vegetable crops: green bean - 'Oregon 91 G'; cucumber - 'Sunre 230'; potato - 'Russet Burbank'; carrot - 'Royal Chantenay'; tomato - 'Oregon Spring'; broccoli - 'Cruiser F1 RS'; and table beet - 'Detroit Dark Red' were randomized within B treatment plots. Crops were planted in single rows 6.9 meters long and 0.91 meters apart.

The fall application consisted of 5 kg B/ha as Solubor dissolved in 76 liters of water, spray applied to the soil and disc-incorporated on October 13, 1986. The other boron treatment, a spring application of 5 kg B/ha was made on April 25, 1987. Prior to planting in the spring all plots were fertilized with 36 kg/ha N, 109 kg/ha P and 36 kg/ha K, broadcast and disc-incorporated. An additional 32 kg

N/ha was sidedressed six weeks after planting on potatoes, cucumbers, beets and broccoli. All crops except tomato were planted from seed on May 11, 1987. Greenhouse grown tomato plants were transplanted on the same date with an in-row spacing of 69 cm. Single-drop seed potatoes were planted with an in-row spacing of 23 cm. After stand establishment, broccoli and cucumber were thinned to an in-row plant spacing of 25 and 36 cm, respectively.

Pesticides were used as needed to control insect and disease problems. Pesticides used were Sevin, diazinon, methomyl and Disyston 15% G for insect control and manex for blight control in potatoes. Weed control was accomplished by manual and mechanical means. Plots were irrigated by overhead sprinklers at seven to ten day intervals so that soil moisture was not limiting.

Replicated soil samples were taken at depths of 0-23 cm and 23-46 cm on August 1 for hot water soluble boron determination (Table 1). Soil samples from control plots were also analyzed for pH, soil texture, organic matter (OM) and cation exchange capacity (CEC) in the Oregon State University Soil Testing Laboratory.

All replicated leaf samples were prepared and analyzed at the Horticulture Plant Analysis Laboratory, Oregon State University. Leaf samples were washed, dried at 70° C and ground through a 20 mesh screen. One-half gram samples of leaf tissues were ashed at 500° C and diluted with 10cc 5%

HNO_3. Mineral analysis was done on an ICAP spectrometer.

'Oregon 91 G' green beans were sampled at 10% bloom on June 27 in which ten uppermost fully expanded leaves per plot were collected for boron determination. Five whole bean plants/plot were sampled for dry weight determination. Plots were harvested on July 20, and pods were weighed and graded for sieve size distribution.

Cucumbers were harvested four times, July 14 and 26, August 5 and 18. Yield and size distribution (fruit diameter) were recorded for each harvest . Size distribution was determined on a 6.8 kg subsample. Fifteen most recently matured leaves/plot were collected on the first harvest date and analyzed for boron concentration.

The fourth leaf from the growing point was chosen for boron determination in 'Russet Burbank' potato. Samples of 15 leaves/plot were taken on July 7. Potatoes were harvested on October 10 and graded for U.S. #1, #2 and process grade according to USDA Standards for fresh potatoes.

Carrot leaves were sampled when the largest roots were about 2.5 cm in diameter. The sample consisted of 15 recently matured leaves and petioles. Carrot roots were harvested on October 1 and 2, weighed and size distribution determined (diameter of roots).

Leaf tissues of tomato were sampled for boron on July 25 when the fruits began to show first color. The fourth leaf from the growing point was sampled from five plants per plot. Tomatoes were harvested when fruits were light red to red ripe. Harvests were on August 10, 21, 30 and September 7. Fruits were weighed and counted and twenty fruit per treatment were examined for symptoms of boron deficiency.

The first mature leaf below the head (5 leaves/plot) was sampled when broccoli heads were approximately 2.5 cm in diameter. Broccoli heads were harvested on July 29, trimmed to 16.5 cm length and weighed. The trimmed heads were then cut longitudinally to ascertain the level of hollow stem and internal stem discoloration.

Table beet leaves were sampled for boron determination when the plants had approximately 12 leaves and the largest roots were 2.5-3.8 cm in diameter. Leaf samples consisted of 15 recently matured leaves per plot. Beet roots were harvested on September 15, weighed and size distribution determined (diameter of roots). Twenty-five roots per plot were cross-sectioned to determine the incidence of canker from boron deficiency.

Data from all observations were assessed by analysis of variance and treatment means were compared by LSD.

RESULTS AND DISCUSSION

Fall or spring applications of 5 kg/ha B increased available soil-B above the soil test values in the control plots. Boron levels were increased in both the 0-23 cm and the 23-46cm depths (Table 1). The predominance of the non-ionized form of boric acid, $H_3(BO)_3$, at soil pH 6.0 facilitates the leaching of applied B. At the 23-46 cm sample depth, the increase above the control values was greatest in the sandy loam soil that received fall B applications. Kubota et.al. (1948) reported that B movement from the surface horizon was greatest in light-textured, slightly acidic soils. Clay content, organic matter content and cation exchange capacity (CEC) are significantly correlated with the adsorption of B in soils (Keren and Bingham 1985).

Boron application increased bean leaf-B concentrations significantly in both the silty clay loam and the sandy loam soils. Leaf-B was highest in spring-treated B plots on both soils. Untreated control plots had the lowest leaf-B levels. Pod yield, grade and plant dry weights from the silty clay loam soil did not show treatment effects. However, percent of pods in size grades 1-4 was reduced significantly in the spring B treatments on the sandy loam. Boron treatments did not affect total yield and plant dry weights (Table 2).

Table 1. Soil properties and changes in hot water soluble B in resonse to boron application at two test sites, Corvallis, OR.

Textural class	Depth (cm)	pH	Percentage sand	silt	clay	OM	CEC	Boron Treatment None	Fall	Spring
								----mg/kg B----		
<u>silty clay loam</u>	0-23	6.0	7.4	64.2	28.4	2.6	28.1	.39	.68	.81
	23-46							.39	.48	.52
<u>sandy loam</u>	0-23	6.0	62.8	23.4	13.8	1.0	14.9	.20	.37	.42
	23-46							.16	.33	.25

Table 2. Effect of boron application on bean leaf-B, pod yield and size distribution and plant dry weight.

Soil type	Boron tmt.	Leaf-B (mg/kg)	Pod Yield (t/ha)	Yield, % grade 1-4	Dry weight, g/5 plants leaves	Dry weight, g/5 plants stems
silty clay loam	none	33.3a	21.6	29	13.3	10.2
	fall 5 kg/ha	41.0ab	19.3	31	12.0	9.6
	spring 5 kg/ha	48.0b	19.0	31	11.8	9.5
LSD .01		8.4				
LSD .05		5.6	ns	ns	ns	ns
sandy loam	none	35.5a	17.4	49a	13.3	10.6
	fall 5 kg.ha	48.3b	17.7	49a	16.3	13.6
	spring 5 kg/ha	59.5b	18.0	42b	14.6	12.3
LSD .01		12.5				
LSD .05		8.3	ns	5.1	ns	ns

Gupta (1983) reported bean leaf-B levels of <12, 42, and >125 mg/kg as deficient, sufficient and toxic, respectively. However, Gupta and Cutcliffe (1984) reported that tissue B concentrations as low as 60 mg/kg caused toxicity symptoms and reduced yield in field (dry) beans. Though total yield was not reduced in this study, leaf-B levels of 59.5 mg/kg significantly reduced the yield of premium grades of pods (sieve sizes 1-4).

Bean leaf-B levels were higher in all treatments on the sandy loam soil than on comparable treatments in the silty clay loam, even though the hot water soluble (hws) soil B was higher in the silty clay loam (Table 1). Work done on beans at the U.S. Salinity Laboratory at Riverside California showed that in beans grown on a silty clay loam and a sandy loam at equal treatments of excess soil solution B (5 and 10 mg/kg), tissue boron concentrations were roughly twice as high in the sandy loam as in the silty clay loam (Hatcher, Blair and Bower 1959).

Cucumber leaf-B, yield and fruit diameter were not affected by boron application (Table 3). Leaf-B levels from all treatments were within the sufficiency range for cucumbers reported earlier (Gupta 1979).

Boron treatments did not affect potato leaf-B, yield or grade distribution on the silty clay loam plots. Leaf-B on the sandy loam was signficantly higher on spring-treated plots than on untreated control plots. Yield and grade

Table 3. Effect of boron application on cucumber leaf-B, yield and fruit size distribution.

Soil type	Boron tmt.	Leaf-B (mg/kg)	Yield (t/ha)	Fruit size distribution (%)					
				<27mm	27-38mm	39-51mm	52-57mm	58-63mm	>64mm
silty clay loam	none	36.3	91.1	5	18	46	17	6	8
	fall 5 kg/ha	35.0.	91.4	4	20	41	20	6	9
	spring 5 kg/ha	38.5	97.1	5	22	47	16	5	5
LSD .05		ns	ns	ns	ns	ns	ns	ns	ns
sandy loam	none	34.0	76.2	4	31	35	12	3	15
	fall 5 kg/ha	40.0	71.5	7	27	38	12	3	13
	spring 5 kg/ha	43.8	73.1	3	24	36	18	6	14
LSD .05		ns	ns	ns	ns	ns	ns	ns	ns

Table 4. Effect of boron application on potato leaf-B, yield and tuber grade distribution.

Soil type	Boron tmt.	Leaf-B (mg/kg)	Yield (t/ha)	Tuber grade distribution (%)		
				U.S. No. 1 & 2	<48mm	process grade
<u>silty clay loam</u>	none	18.0	93.2	56	17	27
	fall 5 kg/ha	18.0	97.0	54	15	31
	spring 5 kg/ha	21.0	91.1	58	15	32
LSD .05		ns	ns	ns	ns	ns
<u>sandy loam</u>	none	19.5a	69.2	56	23	21
	fall 5 kg/ha	24.0b	56.7	56	25	19
	spring 5 kg/ha	25.3b	66.9	53	25	22
LSD .05		4.1	ns	ns	ns	ns

Yield and grade distribution were not affected (Table 4).

MacVicar et. al. (1946) reported potato leaf-B levels of 22.0-26.1 mg/kg on a sandy loam soil containing 0.36 mg/kg soluble B. Tissue and soil boron levels reported here for the sandy loam site are very similar to these findings. Roberts and Rhee (1990) reported that field plots with 0.3-0.4 mg/kg hws B were adequate for potato production. However, they reported B toxicity to be "eminant" at field application rates of 4.5 kg B/ha. Boron toxicity symptoms were not expressed in either fall or spring applications of 5 kg B/ha in this study.

Carrot leaf-B, yield and root diameter were not affected by boron application (Table 5). Leaf-B levels for all treatments were within the sufficiency range reported earlier (Gupta 1979). Gupta and Cutcliffe (1985) did not show a yield response to applied B (0, 2 and 4 kg B/ha) with leaf-B levels ranging from 36-76 mg B/kg.

Tomato leaf-B, yield, fruit per plant and fruit weight were not affected by boron application (Table 6). Twenty fruit per treatment per harvest were examined for open locule, internal browning and stem end russeting and these disorders were absent. Leaf-B concentrations from all treatments were within reported sufficiency levels (Gupta 1979).

Boron application significantly increased broccoli leaf-B levels which were highest in the fall B plots on

Table 5. Effect of boron application on carrot leaf-B, yield and root size distribution.

Soil type	Boron tmt.	Leaf-B (mg/kg)	Yield (t/ha)	Root size distribution (%)				
				<25mm	26-38mm	39-51mm	52-63	>64mm
silty clay loam	none	33.5	75.0	1	16	49	26	8
	fall 5 kg/ha	32.0	81.4	1	18	45	28	8
	spring 5 kg/ha	32.3	79.4	1	18	48	25	8
LSD .05		ns	ns	ns	ns	ns	ns	ns
sandy loam	none	27.8	70.4	2	20	48	22	8
	fall 5 kg/ha	28.5	68.1	2	16	39	27	16
	spring 5 kg/ha	28.0	58.5	2	26	45	19	6
LSD .05		ns	ns	ns	ns	ns	ns	ns

Table 6. Effect of boron application on tomato leaf-B, yield, fruit number and fruit weight.

Soil type	Boron tmt.	Leaf-B (mg/kg)	Yield (t/ha)	Fruit number (no./plant)	Fruit weight (g/fruit)
silty clay loam	none	44.8	163.9	45	249
	fall 5 kg/ha	45.3	162.5	45	241
	spring 5 kg/ha	42.5	171.7	51	230
LSD .05		ns	ns	ns	ns
sandy loam	none	32.5	156.3	45	227
	fall 5 kg/ha	40.3	152.3	46	210
	spring 5 kg/ha	35.3	141.2	41	221
LSD .05		ns	ns	ns	ns

both soil types (Table 7). Work by Shelp (1988), Gupta and Cutcliffe (1973) and Francois (1986) showed that as soil B increases, broccoli leaf-B increases. Leaf boron levels reported here are within reported sufficiency levels for all treatments. Treatment means for yield and hollow stem and stem discoloration were not statistically significantly different.

Fall and spring applications of 5 kg B/ha significantly increased table beet leaf-B concentrations above control values but root yield and size distribution were not affected. Incidence of boron deficiency (canker) of roots were rare and inconsistent among treatments (data not shown). Reasons for the low incidence of canker in these plots are not clear. Increasing rates of soil applied B (0, 2 and 4 kg/ha) in other studies (Gupta and Cutcliffe 1985) significantly increased leaf-B but did not increase yields. The authors reported boron deficiency symptoms in roots (canker) at leaf-B levels of 32-40 mg/kg. This agrees with Mack (1989) where leaf-B concentrations at 0 and 11.2 kg B/ha were 38 mg/kg and 92 mg/kg, with corresponding canker levels of 33.7% and 13.5%, respectively.

Table 7. Effect of boron application on broccoli leaf-B, yield and incidence of hollow stem and stem discoloration.

Soil type	Boron tmt.	Leaf-B (mg/kg)	Yield (t/ha)	% of 18 heads affected by hollow stem and stem discoloration
<u>silty clay loam</u>	none	37.5a	18.9	46
	fall 5 kg/ha	43.5b	19.4	54
	spring 5 kg/ha	40.5ab	19.0	53
LSD .01		5.2		
LSD .05		3.4	ns	ns
<u>sandy loam</u>	none	25.8a	16.0	21
	fall 5 kg/ha	39.8b	15.8	17
	spring 5 kg/ha	34.0c	16.5	17
LSD .01		7.4		
LSD .05		4.8	ns	ns

Table 8. Effect of boron application on beet leaf-B, yield and root size distribution.

Soil type	Boron tmt.	Leaf-B (mg/kg)	Yield (t/ha)	Root size distribution (%)			
				<50mm	51-75mm	76-100mm	>101mm
silty clay loam	none	35.5a	42.4	11	58	28	3
	fall 5 kg/ha	56.0b	43.1	10	54	29	7
	spring 5 kg/ha	49.8b	46.0	11	56	27	6
LSD .01		8.2					
LSD .05		5.4	ns	ns	ns	ns	ns
sandy loam	none	31.0a	32.8	16	62	22	0
	fall 5 kg/ha	55.0b	37.2	13	64	20	3
	spring 5 kg/ha	49.5b	35.3	13	59	24	4
LSD .01		10.6					
LSD .05		7.0	ns	ns	ns	ns	ns

SUMMARY AND CONCLUSIONS

Boron at the rate of zero (control) or five kg B/ha (Solubor 20.5% B) was fall or spring applied to a silty clay loam and a sandy loam. Seven vegetable crops (green bean, cucumber, potato, carrot, tomato, broccoli and table beet) were grown in each of the boron treatments on the two soils. Replicated soil samples at two depths were analyzed for boron content. Soil physical properties (textural analysis), pH, organic matter content and cation exchange capacity were determined from control plot samples. Leaf-B analysis, yield and quality were measured for each crop.

Fall or spring application of B increased B soil test values. Soil boron concentrations were lower in the light textured sandy loam than in the silty clay loam soil for all tretments.

Yield treatment means were not statistically significant among the three boron treatments on either soil type. The percentage of bean pods in premium grades was depressed by the spring B application to the sandy loam soil.

Leaf-B concentrations were significantly higher from B applications than for controls in beans, broccoli and table beets on both soils. Potato leaf-B levels showed significant differences from B application only on the sandy loam soil. All leaf-B levels were within reported sufficiency levels.

Vegetable crops have been rated as to their relative tolerance to boron. The vegetable crops used in this study were, in increasing level of tolerance to boron: green beans, cucumber, potato, carrot, tomato, broccoli and table beet. However, under the conditions of this study, soil applied B at rates of zero or 5 kg/ha did not cause plant deficiency or toxicity symptoms in any of the crops observed. Soil applied B increased leaf-B levels in most crops.

Though the reported range between boron deficiency and toxicity is relatively narrow for many crops, under the experimental conditions experienced here the 5 kg B/ha rate was neither detrimental nor beneficial to yield and quality attributes of the seven crops. However, these results are useful for reference in that the seven crops were grown under the same conditions on two soil types and soil and leaf boron concentrations were measured along with cooresponding yields and quality characteristics.

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