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Boron Composition of Alfalfa in Utah as Related to Soils and Irrigation Waters

Robert N. Radtke Jr.

BORON COMPOSITION OF ALFALFA IN UTAH AS RELATED TO SOILS AND IRRIGATION WATERS

by

Robert N. Radtke Jr.

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Robert N. Radtke Jr.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES

List of Figures

ABSTRACT

Boron Composition of Alfalfa in Utah as Related to Soils and Irrigation Waters

by

Robert N. Radtke Jr., Master of Science

Utah State University, 1986

Major Professor: Dr. David W. James
Department: Soil Science and Biometerology

Eighteen field plots at 15 locations were selected throughout the state to evaluate the status of the boron content in irrigation waters, soils, and alfalfa (Medicago sativa) plant tissue under irrigated conditions.

No boron deficiency symptoms were observed in any of the alfalfa plants at any of these locations, nor were any of the plant tissue boron levels inadequate. Only two locations were found in which the alfalfa plants exibited toxicity symptoms. These locations were along the Indian and Antelope Creeks in Duchesne County which contain high boron levels in the water. All the alfalfa and soil tested and irrigated by either Indian or Antelope Creek contained high levels of boron. Indian and Antelope Creek waters are the only ones tested and found to contain, naturally occuring, high levels of boron in Utah.

The light sandy soils were found to contain less available boron than the heavier clay soils. The sandy soil of the Grand County location at Moab showed no available soil boron, while the clayey soils in Duchesne County irrigated with high boron waters were the only soils found to contain excessive levels of available soil boron.

The application of 2.8 kilograms of boron per hectare in the form of Solubor significantly increased the available soil boron content by 22.86 percent and the plant tissue boron content by 19.07 percent in the Cache County plots.

The 12 alfalfa varieties grown in the Morgan and Tooele County plots showed significant differences with respect to location and tissue boron contents when the results of the two locations were combined. Overall, variety Deseret had the highest average boron content of 69.5 milligrams boron per kilogram and AS-49R contained the lowest boron content of 54.88 milligrams boron per kilogram.

The soil boron and the water boron contents were found to be highly correlated and they appear to be measuring the same thing. The plant tissue boron content was found to be satisfactorily estimated from either the irrigation water boron content ($Y = 69.91 + 13.64X$; $R^2 = 0.79$) or the available soil boron content ($Y = 63.15 + 7.66X$; $R^2 = 0.82$).

(68 pages)

INTRODUCTION

Of the essential micronutrients, boron is one that has been intensively studied but poorly understood. Boron is required in varying amounts by all higher plants for proper growth and development depending on the plant species and genotype. The dicotyledonous plants generally require more than monocotyledonous plants. Generally, the range between deficiency and toxicity for most plants is fairly narrow.

In humid environments where the soil pH tends to be acidic the available soil boron tends to be more soluble and thus more readily available to plants. The available boron, however, is easily leached through the soil profile by the high amounts of precipitation. This generally causes a deficiency of boron to the crops of these regions.

In arid to semi-arid areas where the soil pHs tend to be higher, soil boron generally tends to become less available to plants due to the chemical reactions and increased soil adsorption. However, because of the limited precipitation available to move or leach boron through the soil, there may actually be more available boron found in the soil solution than in the more humid environments. This available boron, may cause toxicity problems to plants due to a possible build up or concentration in the soil profile, especially if the plant is not tollerant to high levels of boron.

In arid areas some of the boron minerals are readily soluble. This may cause a harmful build up of boron in the soil depending on how irrigation water is managed. Most of the irrigation waters in Utah contain very low levels of boron, and only where the few soils found to be high in natural occuring boron do the waters contain a high amount of boron also.

For this research, fifteen locations were selected to correlate the boron in soils and irrigation waters with the boron in alfalfa grown on the sites. No yield data was collected for this study. Plant and soils were only collected to be analyzed for boron content. This study was conducted to determine if there were any areas in the state where problems for alfalfa might occur due to boron deficiency or toxicity.

The specific objectives of this work were:

1) To survey typical Utah alfalfa fields for soil and plant boron content.

2) To determine if there are differences among varieties in alfalfa boron content.

3) To determine to what extent the boron composition of irrigation waters affects the soil and plant boron contents.

LITERATURE REVIEW

Soil Boron

The average amount of boron in the lithosphere is approximatly 10 mg/kg (Nemodruk and Kavalova, 1965). It is generally considered, however, that soils have a total boron content which ranges from 20 to over 200 mg/kg (Berger and Pratt, 1963). Generally less than 5% of the boron is in a soluble form and available to plants (Gupta, 1979). Soil boron is either fixed or water soluble and generally is present as a borosilicate, sodium or calcium borate, organically combined, or an adsorbed borate ion (Chrudimsky, 1970).

Factors Affecting Boron in the Soil.

Soils in which large amounts of boron are likely to be found are: 1) those derived from marine sediments; 2) arid soils; 3) soils derived from parent material rich in boron; 4) soils originating from geologically young deposits.

The soils where boron deficiencies are more likely to occure are: 1) soils which originated from acid igneous rocks or fresh water sedimentary rocks; 2) naturally acid soils which are highly leached; 3) light textured sandy soils; 4) acid peat and muck soils; 5) highly alkaline soils, especially those containing free lime; 6) irrigated soils where the irrigation water has a low boron content and where salt or carbonate deposits occur; and 7) soils low in organic matter (Norrish, 1975; Bradford, 1966; Nemodruk and Karalova, 1965).

Acid soil conditions. In humid regions where soils are more acidic, due to the high rates of leaching, boron is generally more deficient for plants than in more arid areas (Beeson, 1945). The main source of boron in these soils is tourmaline, a borosilicate mineral which is very hard, highly refractive and resistant to weathering (Gupta, 1979). As tourmaline weathers boron slowly becomes available for plant use. However, this available boron is leached away rather quickly where high rainfall occurs. One reason the soluble boron may be leached so easily from the soil profile may be due to the fact that it is found mainly in the form of boric acid. Under the lower soil pH of acid soils boric acid is not deprotonated and therefore not found in an ionized form (Mengle and Kirby, 1982). This significantly reduces soil sorption of boron (Gupta and Cutcliffe, 1978; Graham, 1957). Under acid conditions natural boron is undoubtedly released too slowly from boron containing minerals to meet the needs of most crops (Berger and Pratt, 1963).

The availability of boron in acid soils appears to be correlated with the soil organic matter. Generally, boron is less available for plants as the soil pH increases over 7.0 or falls below 5.0. The reduction of available boron with lower pH correlates well with the reduction of the organic matter under these conditions (Berger and Troug, 1945). Organic boron is released as a soluble form by microbial decomposition. Thus, water soluble boron is positively correlated with the organic matter of the soil (Gupta, 1968; Berger and Troug, 1945). Berger and Pratt (1963) and Page and Paden (1954) considered organic boron to be the main source of water soluble boron in humid areas.

Alkaline soil conditions. Arid or semi-arid soils generally have higher pH values the soils of humid environments. It is possible that in these arid conditions, since leaching of the soil profile is not a significant factor, the subsoils may be higher in available boron than the surface soils. It appears that under certian conditions available boron may be high (Kanwar and Shah Singh, 1961; Haas, 1944; Eaton, 1935).

There appears to be a negative relationship between soil pH and plant boron content when pH levels of the soil are greater than about 6.5 (Gupta and MacLeod, 1977). Wear and Patterson (1962) reported that as the soil pH increased the uptake of boron by alfalfa decreased. At higher soil pH boron movement and availability is decreased by the increased adsorption of boron onto soil particles by a change in the form in which the boron is found (Okazzki and Chao, 1968; Hingston, 1964; Kubota et al., 1948; Olson and Berger, 1946). In the upper pH range of alkaline soils the boric acid tends to act as a Lewis acid, accepting OH^- and thus forms the borate ion; $B(OH)_3 + H_2O = B(OH)_4^- + H^+$, pk = 9.0 (Parfitt, 1978). The borate ion may then be adsorbed on to clay minerals, colloids, sesquioxides and carbonates in the soil reducing availability to plants. Hingston et al. (1972) found maximum boron adsorption at pH 9.0. Adsorption of the borate anion may be found on the anion exchange sites of soil particles or due to ligand exchange. In the case of ligand exchange the OH^- of the adsorbing surface is replaced by the borate ion (Parfitt, 1978). This ligand exchange is associated with a chemical reaction where the anion becomes attached to a metal ion and is fairly anion specific. Also, borate ions may react with surface hydroxyls to form a borate-diol complex which will also reduce boron availability to plants (Sims and Bingham, 1968; 1967). Free calcium and magnesium in the soil will also tie up the borate ion in the form of metaborates. Colwell and Cummings (1944) found that calcium metaborate forms an endless chain structure. They suggested that polymerization of calcium metaborate would decrease the plant uptake of boron. Berger and Troug (1945) found that in alkaline soils, the soil reaction and available calcium seem to have a greater effect on the availability of boron than the organic matter content. Gupta (1979), however, reported that soil pH effects on availability of boron may be more important for some soils than others.

Soil texture. Soil texture will influence boron availability in a soil system. Sandy soils generally contain less available boron than do heavier textured soils (Kubota et al., 1948). A high correlation was found by Hatcher and Bower (1958) between the total surface area of three soils and their adsorptive capacity for boron, with the heavier clay type soils having a greater ability to adsorb boron, as the borate ion, than the lighter soils (Olson and Berger, 1946). Also, in lighter soils the soluble boron leaches faster than in heavier soils (Winsor, 1952; Wilson et al., 1951; Kubota et al., 1948).

Soil moisture. Adsorption or fixation of boron by soils is influenced by the soil moisture regime. Wetting and drying of a soil will increase boron fixation (Bigger and Fireman, 1960; Parks and White, 1952).

Irrigation waters. The content of boron in irrigation water will also have an influence on the amount of available soil boron. In arid regions, water may have a high boron content because of the more soluble forms found in them (Berger, 1949). This is especially true if the stream originates in or passes through an area of marine clays or shales (Norrish, 1975; Nemodruk and Karalova, 1965).

Some researchers consider water with a boron content greater than 2 mg/kg unsuitable for irrigation purposes for any crop (Magistad and Christiansen, 1944). Others consider the crop sensitivity to boron in determining the suitability of the water for irrigation purposes (Wilcox, 1948a; 1948b).

Most of the waters in Utah used for irrigation have low concentrations of boron and pose no threat of injury to crops. Known areas with naturally high levels of boron in irrigation water are found in the Uintah basin around Duchesne (Thorne and Thorne, 1951). The streams in this location pass through an area of Mancos shale, a saline marine deposit, which may be the origin for the boron of the streams (Norrish, 1975).

Plant Physiology of Boron

Boron uptake. The water soluble boron fraction is available for immediate plant uptake. Boron appears to be taken up by plants as undissociated boric acid, rather than borate ions, in a passive nonmetabolic process (Bowen and Nissen, 1976; Oertli and Grquevic, 1975; Bingham et al., 1970; Elseewi et al., 1968; Tanaka, 1967; Oertli, 1963). Gupta (1979) working with pea plants and Elseewi et al. (1968) working with barley found that the boron absorption by these plants was pH dependant with sharp reductions of boron uptake occuring in substrates with pH levels ranging from 7.3 to 7.5 and with a greater uptake in the pH range below 7.3 to 6.5. Below pH 6.5 no definate trend for plant boron content has been found (Gupta and MacLeod, 1977).

Absorption of boron by plants was not affected by metabolic inhibitors in the nutrient media or by temperature (Elseewi et al., 1968).

Boron translocation. Within plants boron is a realitively immobile micronutrient. Boron deposited within a leaf appears to remain there for most plants (Eaton, 1944). However, some researchers found boron to be translocated out of older peanut leaves to younger leaves when the plant contained over a certian base level (Morrill et al., 1977). The amount of boron required by plants for normal growth depends on the plant species and possibly the plant genotype. Average boron levels for grains will generally run between 0.6 to 36 mg/kg while forage legumes require slightly higher levels of boron, averaging between 7 and 57 mg/kg (Nemodruk and Karalova, 1965; Wall and Andrus, 1962).

Factors which increased transpiration in barley seedlings also increased boron accumulation in the leaf tips, while factors which decreased water uptake resulted in less boron movement toward the leaf tips. However, there was no equivalence between boron and water uptake found by Oertli (1963). This tends to support the idea that boron is translocated mainly through the xylem and accounts for its accumulation in the leaf tips and margins (Jones, 1970).

The movement of boron in the xylem stream rather than in the phloem, explains why boron deficiency always begins at the growing points. This is similar to the behavior of calcium which is also virtually absent from the phloem sap (Mengel and Kirby, 1982). Oertli (1960) found that boron moves away from the veins in the leaf to the tips and marginal areas. In net veined leaves boron becomes more concentrated in the marginal and interveinal areas, while

Kohl and Oertli (1961) found the highest concentrations of boron in the leaf tips in plants with parallel veins. Another area of high boron concentration occurs in certain plant organs such as the anthers, stigma and ovaries (Syworotkin, 1958).

Function of boron in plants. Boron appears to be essential for plants and not animals. For proper growth and development of the meristematic regions of plants a continuous supply of boron is required (Gupta, 1979). The reason for this requirment of boron is not yet known, nor is the biochemical role of boron well understood as it has not yet been shown to be a primary part of an enzyme system (Jackson and Chapman, 1975). It has been shown, however, that boron is involved in the synthesis of uracil (Birnbaum et al., 1977). Uracil is an essential component of RNA and if the RNA production is affected by a deficient amount of boron in the plant, ribosomes cannot be formed which in turn affects protein synthesis. If these functions are inhibited, the entire process of meristematic growth of the plant is hindered (Hundt et al., 1970).

A deficiency of uracil in plants results in other problems too. Uracil is the precursor to uridine diphosphate glucose, an essential coenzyme required for the formation of sucrose, the most important sugar transport form (Hall and Baker, 1972). If the formation of sucrose is disturbed, the translocation of assimilates in the phloem is also affected (Mengle and Kirby, 1982).

Van de Venter and Currier (1977) also found an increased production of callose with boron deficiency, and thereby an increased production of callose plugs, which can block sieve plate pores. This blockage also has an influence on phloem transport but researchers are not sure if increased callose production is related to the inhibition of sucrose synthesis.

Some work with metabolism - linked ion transport suggests that boron may also have a direct effect on the confirmation and activity of specific membrane components of the cell (Pollard et al., 1977). They suggested that a possible mechanism for membrane control by boron is its reaction with polyhydroxy compounds which would influence the activity and integrity of the membrane.

Wagner and Michael (1971) found that when boron is deficient the production of cytokinins was inhibited. While other evidence shows that auxins tend to accumulate in boron deficient tissues. Some researchers feel that necrosis in the growing points of boron deficient plants is caused by an accumulation of auxin (Coke and Whittington, 1968). They suggest that boron protects the IAA oxidase system by complexing with inhibitors of IAA oxidase. Another possible correlation between boron deficiency and auxin metabolism was shown when the onset of the necrotic disorder in lettuce known as "tipburn" occurs with boron deficiency there was an increase in auxin activity (Crisp et al., 1976). Shkolnik (1974) also feels that the necrosis in plants associated with boron deficiency is primarily due to an accumulation of excess auxins and phenols in the plant tissue.

Detection of Boron Deficiency and Toxicity

Plant species have different requirments for boron and different tollerances to boron. Therefore, no single amount or mean composition can be used for evaluating toxicity or deficiencies. Alfalfa, for example, has a high requirment for boron and is fairly tollerant to high levels of boron, while wheat has a low boron requirment and is susceptable to high soil boron levels (Gupta, 1979; Berger, 1949). As a rule, each plant group needs to be looked at separately.

There are three ways the boron status may be evaluated for a crop. The easiest is by visual observation, looking for deficiency or toxicity symptoms. The other two methods require plant and soil analyses (James and Weaver, 1964).

Visual symptoms. Boron deficiency symptoms in alfalfa occur first and most severly at the leaf tips and in younger growth because boron is fairly immobile and the younger growing tissues have a higher requirment for boron than older tissue (Sprague, 1964). Deficiency symptoms include: yellowing of younger leaves with upper plant parts becoming yellow or redish (Bergmann and Neubert, 1976; Gupta, 1972; James and Weaver, 1964); internodes near growing tips become shorter and plants take on a rosette appearence (James and Weaver, 1964; Berger, 1962); flowers may fail to form and buds may appear as white or light brown tissue (Nelson and Barber, 1964). In severe cases the terminal bud may die and upward growth or expansion stops (James and Weaver, 1964).

Boron toxicity symptoms in alfalfa begin with a yellowing or burning of the edges of the older leaves (Gupta, 1972 ; James and Weaver, 1964), followed by the whole leaf turning yellow and necrotic resulting in premature leaf drop (Bradford, 1966). In extreme cases the whole plant may die (James and Weaver, 1964).

Visual symptoms become apparent only after some damage to the plant has occured for either boron deficiency or toxicity. Corrective action to bring about immediate recovery is unlikely but something might be done to overcome the problem in the future. For a deficiency, boron could be added as a foliar spray or fertilizer to overcome the problem. For toxicity problems, if the plant has not been killed, then it may be possible to irrigate with low boron waters, if any are available, in an effort to leach away the soluble boron. On acid soils the addition of lime may tie up some of the excess boron and reduce the total amount available to plants.

<u>Soil boron content.</u> Soil sampling and analsis can reveal the status of the available boron. Soil analysis allows for an initial assessment without waiting for any plant damage to occur. The total soil boron status does not have any real significance to the plant on a short term

basis because it is mostly unavailable. However, research on some soils has shown a positive correlation between total soil boron and the amount of available boron (Gupta, 1968). The availability of boron to plants by soil testing is generally done using a hot water extraction method. This is much easier than measuring total boron. The hot water method measures soluble, and therefore available, boron in the soil. Uptake of boron by plants correlates well with the hot water soluble boron. (Farrar, 1975; Hill and Morrill, 1974; Reisenauer et al., 1973).

Work done on alfalfa by Reinsenauer et al. (1973), Mortvedt and Osborn (1965), Baker and Cook (1943) indicated that when the hot water extractable boron content was below 1 mg/kg soils may not be able to supply sufficient boron for normal plant growth. Stinson (1953) felt that alfalfa fields in Illinois became deficient when the available boron was less than 0.5 mg/kg. When hot water extractable boron is between 1 and 5 mg/kg the soil should be able to supply adequate amounts of boron to crops and levels above 5 mg/kg soluble boron in the soil may produce toxic effects for many crops. Along with the reported critical soil levels, factors such as, type of crop grown, soil type, soil moisture regime, percent organic matter, soil pH and stage of plant maturity all have some bearing on the ability of the soil to provide boron for normal plant growth.

Plant boron content. Both plant and soil analyses are used to determine the ability of soil to supply boron and each has advantages and weaknesses. Gupta and Munro (1969), Ouellette and Lachance (1954), and Smith (1948) consider plant analyses to be a better index of boron availability than hot water soluble boron in soil. However, as already indicated soil test can indicate the availability of boron in a field before a crop is planted, while plant analysis requires a crop to be growing. This may lead to some yield reductions at first due to an improper level of boron.

Plant sampling techniques need to be consistant from plant to plant and season to season because there can be considerable variation in the boron content with time and part sampled (James and Weaver, 1964). The top 7.5 to 10.2 cm of an alfalfa plant should be collected just prior to harvesting, with the first cutting being the best time to sample (James and Weaver, 1964). Meyer and Martin (1976) reported that when whole tops of alfalfa, at early bloom, contained less than 15 mg/kg boron dry weight the plants were deficient with respect to boron, while Neubert et al. (1970) and James and Weaver (1964) considered the deficiency level to be less than 20 mg/kg. Meyer and Martin (1976) considered 20 to 40 mg/kg to be a sufficient level and over 200 mg/kg to be a toxic concentration of boron in alfalfa. Neubert et al. (1970) reported 31-80 mg/kg as being sufficient and over 100 mg/kg a toxic level of boron in plant tissues. Any deficiency or toxicity symptoms may begin to appear when levels in the plant approach those reported. The levels of boron in plant tissue are influenced by the available boron in the soil and or irrigation waters (Reisenauer et al., 1973). The occurance of visual symptoms may also be affected by environmental conditions along with the actual boron level in the soil or plant (Gupta, 1979; Tanaka, 1966).

Correcting Boron Deficiency or Toxicities

Boron deficiencies are corrected by application of boron fertilizers. Some of the more common types are: Borax ($Na_2B_4O_7 \cdot 10\ H_2O$), 11% B ; boric acid ($H_3BO_3$), 17% B ; boron frits ($Na_2B_4 \cdot X\ H_2O$), 10-17% B ; and Solubor ($Na_2B_4O_7 \cdot 5\ H_2O + Na_2B_{10}O_{16} \cdot 10\ H_2O$), 20-21% B (Gupta, 1979). A major problem with boron fertilization is the narrow range of concentrations from a deficient to a toxic level. If too much boron is applied, crop growth may be effected as much as by the origional deficient level (Gupta, 1979). Morrill et al., (1977) found that by using borosilicate glass frits, most of the problems associated with over fertilization could be avoided. These glass particles release boron at a slow rate into the soil solution, thereby reducing the risk of a rapid concentration buildup. If the soil is alkaline it can potentially adsorb fair quantities of boron (Gupta,1979; Berger, 1949), then a foliar or banded application of boron may be more efficient than broadcast applications (Mengle and Kerby, 1982).

Toxic levels of boron in the soil, which are fairly rare, are harder to remedy than deficient levels. The addition of calcium or magnesium by liming of acid soils may help reduce the amount of soluble boron available to plants (Judel, 1977; Wolf, 1940). A better method to reduce toxic levels of soluble boron in the soil is to irrigate heavily with low boron water (Judel, 1977). In some areas of high soil boron, however, the high boron in the soil may be due to a high level of boron in the irrigation water. In this case the amount of high boron - containing irrigation water applied may need to be reduced to prevent a greater buildup of boron. In this case a different crop may need to be grown, or a more boron tollerant variety grown. Without a more boron tollerant crop or low boron containing waters on a soil with high calcium there is no economical method available to remove excess boron from the soil or water (Wilcox, 1948b).

MATERIALS AND METHODS

Field Plot Study

Fifteen alfalfa producing sites throughout the state were chosen for this research. Two locations were Dr. Jim Bushnells alfalfa variety trials. No yield data was collected for this study. The plants, soils and waters which were collected were only for analytical purposes. Organic carbon for each soil location was estimated by the loss-on-ignition method described by Ball, (1964), and modified by Davies (1974).

Soil types and the estimated organic carbon % along with an estimate of carbonates present in the top 25 cm of the soil at the respective sites are given in Table 1. Figure 1 shows the approximate geographical location of each plot.

During the summer of 1984, alfalfa variety trials in Morgan and Tooele Co. were sampled for boron analysis. The twelve varieties sampled were: WL-309, WL-312, WL-318, Agate, Anchor, AS 49R, Dawson, Deseret, Lahontan, Ranger, Vernal, and Washoe. These varieties were established in a completely randomized design with four replications. Yield data and results for these varieties was collected and compiled for Dr. Jim Bushnell (1985).

At the Evans research farm in Cache County during the summer of 1984, boron in solution as Solubor (21% B) was

Table 1. Site number, location, soil type, estimated organic carbon %, and presence of $CaCO_3$ at plot sites.

Site #	Location	Soil Series	O.C. % (a)	$CaCO_3$ (b)
1.	Cache County -B	Nibley silty clay loam	1.70	No
2.	Cache County +B	Nibley silty clay loam	1.70	No
3.	Weber County	Kidman fine sandy loam	0.34	No
4.	Morgan County	Yates loam	1.35	No
5.	Tooele County	Tomas loam	1.40	Yes
6.	Duchesne County	Neola sandy loam	0.61	Yes
7.	Duchesne County	Billings silty clay	2.10	Yes
8.	Duchesne County	Chipeta silty clay loam	1.15	Yes
9.	Duchesne County	Chipeta silty clay loam	1.15	Yes
10.	Duchesne County	Chipeta silty clay loam	1.40	Yes
11.	Duchesne County	Chipeta silty clay loam	1.40	Yes
12.	Duchesne County	Billings silty clay	1.30	Yes
13.	Duchesne County	Billings silty clay	0.89	Yes
14.	Duchesne County	Billings silty clay	0.66	Yes
15.	Sevier County	Redfield loam	0.22	Yes
16.	Sevier County	Redfield loam	0.27	Yes
17.	Iron County	Escalante loam	0.08	Yes
18.	Grand County	unknown (c)	0.01	Yes

(a) O.C.% estimated by loss-on-ignition method

(b) presence of $CaCO_3$ was estimated in the top 25.5 cm of soil by dillute HCL and effervescence

(c) representative soil series could not be found in the S.C.S. soil survey map for this area

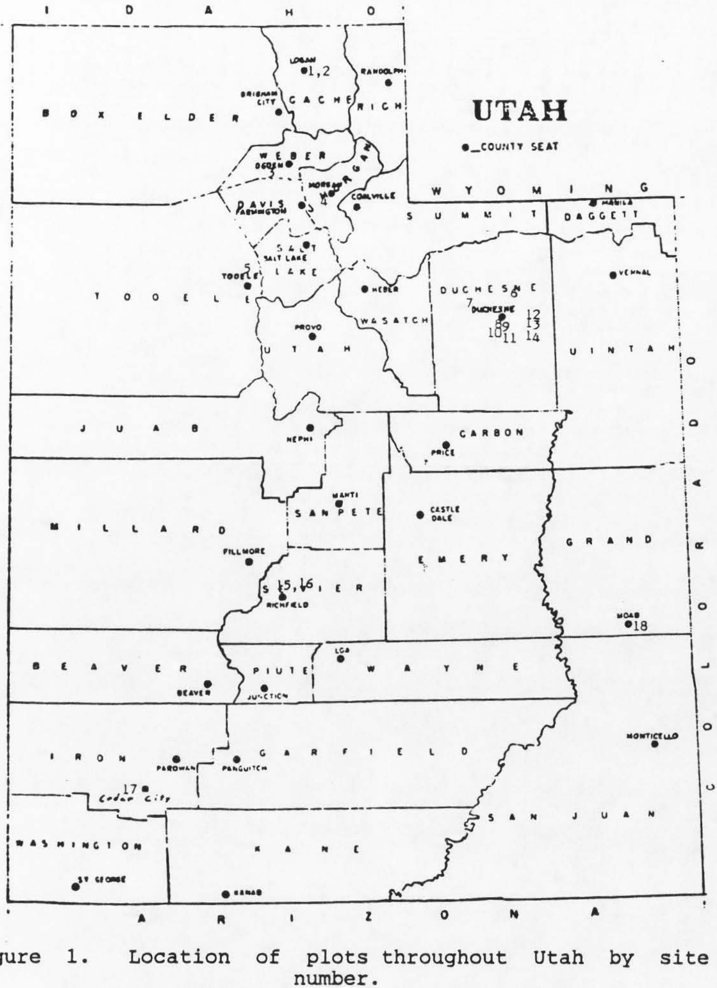

Figure 1. Location of plots throughout Utah by site number.
(see table 1 for soil description)

applied as a treatment on two 2.44 meter wide strips at the rate of 2.8 kg boron per hectare with check strips being adjacent the treated strips. The Solubor was not recieved until well after the first crop was growing, therefore, application of the treatment was postponed from the first crop to the second crop. The treatment application was made with a hand powered boom sprayer after removal of the first crop and before significant regrowth of the second crop began. No boron treatments were applied at any other location.

Plant Sampling

The alfalfa was sampled in the early bloom stage, taking the top 10 cm off 1 stem from about 20 different randomly selected plants to get a representative sample of the plot. The samples were transported in plastic bags to reduce the possibility of contamination. They were oven dried at 40^{o} C and ground in a stainless steel Whiley mill to pass a 1 mm screen.

Irrigation Water Sampling

Irrigation water quality data reported by (Thorne and Thorne, 1951) ,recently updated and supported by James and Jurinak (unpublished data), was used for most of the water quality information. For this thesis, waters were sampled for boron analysis at various locations along Antelope and Indian Creeks in Duchesne County throughout the summer of 1984, as well as from the irrigation well at the Tooele

County site to complement the plant and soil sampling during that same time period. Water was also sampled at the Strawberry River bridge at Duchesne.

Irrigation waters were collected and stored in one liter plastic containers. Water sample came from areas where high boron had been observed previously or where little data was available (Thorne and Thorne, 1951).

Soil Sampling

Soil samples were collected at the time of plant sampling. Cores were collected to represent a cross section through each field to a depth of about 25 cm. The composited samples were air dried and ground to pass a 2 mm screen. At the Evans farm in Cache Co., where boron was applied, soil inside the treated area and adjacent to in the check strips was collected for analysis.

Plant Analysis

All laboratory glassware for this study was acid washed with dilute HCL in order to reduce the possibility of contamination. Pyrex glassware was used. Some research has shown that use of borosilicate glassware does not significantly influence analytical results (Bingham, 1982; Porter et al., 1981).

One half gram of ground plant material was mixed with 0.07 grams of calcium hydroxide in a ceramic crucible. This was ashed in a muffle furnace at 550^{o} C for five hours. The ashed material was then digested with 2 ml of 6N

HCL with the pH adjusted to between 7 - 8 with 1:1 ammonium hydroxide. The digest was transferred to a 50 ml volumetric flask and diluted to volume with distilled water. Boron concentration of the extract was determined with a Coleman 54B spectrometer at 430 nm employing the Azomethine-H colormetric procedure as described by Wolf (1971).

Soil Analysis

The available boron content of the soil was determined using the hot water extraction method (Farrar, 1975). Low boron glassware (vycor) was used along with regular pyrex in order to compare the results. Both types of glassware were acid washed to prevent contamination. Ten grams of soil was placed in a beaker with 20 ml of 0.02 M $CaCl_2$. The solution was placed on a hot plate with a water cooled reflux condensor on top. The solution was boiled for exactly 5 minutes. The beakers were immediatly filtered through a Whatman #2 filter. The extract was collected in plastic containers and analyzed for boron using the Azomethine-H method (Parker and Gardner, 1981; Wolf, 1971).

Organic Matter Estimation

The soil organic matter was estimated using the method described by Ball (1964) as modified by Davies (1974). (The latter used a slightly lower oven temperature, 430° C rather than 475° C). The soil was oven dried at 105° C and then a subsample was weighed into a ceramic crucible and placed in a muffle furnace at 430^{o} C for 24 hours. The soil was then re-weighed and the organic carbon % calculated from the % weight lost using the equation $y = .458x - 0.4$, where x is the % loss on ignition and y = the % organic carbon (Ball, 1964). Ball's prediction equation was used rather than Davies (1974) because it gave results closer to the reported organic carbon value reported by the Soil Conservation Service for the Nibley silty clay loam soil at Cache County. This method reportedly does not affect the innerlattice water of hydration and reduces error potential of higher temperatures.

Irrigation Water Analysis

The irrigation waters were analyzed for boron using the Azomethine-H method (Wolf, 1971).

Statistical Analysis

Statistical tables used and refered to for calculating significant differences came from a text book by Dowdy and Wearden (1983). An IBM computor using the SAS program was used for some of the statistical analyses.

RESULTS AND DISCUSSION

Soil Boron Results

Available boron. Hot water extractable boron was measured using two different types of glassware. Regular pyrex, a borosilicate, and Vycor, a low boron containing glass. Table 2 presents the data for the extractable soil boron at each sampling location using both types of glassware. Many feel that low boron glassware should be used when analyzing for boron in soil (Parker and Gardner, 1981; Wolf, 1971) to reduce the possibility of contamination. The results of this study, however, were more in line with work done by Bingham (1982), who reported that the type of glassware should have little effect on the results when analyzing for boron. The widest range between pyrex and vycor at any location was 1.56 mg/kg while at 2 locations both types of glass gave the same results. To determine if there was any significant difference between the two types of glass a t-test was performed. The t-test for the available soil boron measured with two types of glassware is found at the bottom of Table 2. There is no significant difference between the pyrex and vycor lab analyses at the 5% level.

Table 3 presents the boron content for the irrigation water, available soil boron, and plant tissue boron content for the different locations.

Table 2. Difference between Pyrex and Vycor glassware when analyzing for available soil boron.

Location	Hot Water Extractable Boron	
	Pyrex	Vycor
	---mg/kg---	
1. Nibley silty clay loam, Cache County. -B	0.96	1.02
2. Nibley silty clay loam, Cache County. +B	1.21	1.25
3. Kidman fine sandy loam, Weber County	0.56	0.70
4. Yates loam, Morgan County	0.46	0.76
5. Tomas loam, Tooele County	1.57	1.67
6. Neola sandy loam, Duchesne County	0.98	0.60
7. Billings silty clay, Duchesne County	0.56	0.44
8. Chipeta silty clay loam, Duchesne County	10.10	11.62
9. Chipeta silty clay loam, Duchesne County	10.36	9.34
10. Chipeta silty clay loam, Duchesne County	6.57	6.90
11. Chipeta silty clay loam, Duchesne County	7.26	8.18
12. Billings silty clay, Duchesne County	8.00	9.56
13. Billings silty clay, Duchesne County	6.80	7.56
14. Billings silty clay, Duchesne County	7.36	7.78
15. Redfield loam, Sevier County	0.84	0.84
16. Redfield loam, Sevier County	0.98	1.18
17. Escalante loam, Iron County	0.68	0.75
18. Moab, Grand County (a)	0.00	0.00
Mean	3.63	3.90

t(table) = 2.11

t(.05,17) = 1.79 N.S.

N.S.= not significant at 5% level

(a) no representative soil series found

Table 3. Boron content in various Utah soils, irrigation waters, and alfalfa.

Site # + Location		Irrigation mg/l	Available Soil mg/kg	Plant mg/kg
1.	Cache County -B	0.02 (a)	0.99	57.54
2.	Cache County +B	0.02 (a)	1.23	68.43
3.	Weber County	0.04 (a)	0.63	60.00
4.	Morgan County	0.05 (a)	0.58	57.76
5.	Tooele County	0.14	1.62	66.85
6.	Duchesne County	0.06 (a)	0.79	95.00
7.	Duchesne County	0.02 (a)	0.50	63.00
8.	Duchesne County	6.00	10.86	135.00
9.	Duchesne County	6.00	9.85	149.00
9a.	Duchesne County(b)	6.00	9.85	232.00
10.	Duchesne County	2.92	6.74	91.00
11.	Duchesne County	2.92	7.72	132.00
12.	Duchesne County	3.49	8.78	150.00
12a.	Duchesne County(b)	3.49	8.78	254.00
13.	Duchesne County	3.49	7.18	131.00
14.	Duchesne County	3.49	7.57	102.00
15.	Sevier County	0.15 (a)	0.84	78.00
16.	Sevier County	0.15 (a)	1.08	65.00
17.	Iron County	0.08 (a)	0.72	82.00
18.	Grand County	0.05 (a)	0.00	71.50
19.	Strawberry River at Duchesne	0.19	-	-

(a) values from Thorne and Thorne (1951)

(b) samples from plants showing toxicity symptoms "burnt edges" from same site as the preciding site

Except for the Moab location, all the sites had an available soil boron content greater than 0.5 mg/kg which is the deficiency level reported by James and Weaver (1964), Stinson (1953) and Berger (1949). However, the Moab field showed no boron deficiency symptoms for the alfalfa or a deficiency level by plant analysis even though the available soil boron level was 0.0 mg/kg in all four repeated analyses. Apparently the amount of boron was below the sensitivity of the testing procedure (Bingham, 1982). The low level of available soil boron at Moab may be related to the sandy nature of that soil (Gupta, 1979; Wear and Patterson, 1962; Stinson, 1953; Berger, 1949). It appears that the irrigation water at the Moab site is able to supply the majority of the boron required by alfalfa plants for normal growth while leaching any excess boron out of the soil profile.

Only five locations in this study contained hot water extractable soil boron in excess of 5 mg/kg. This was reported by Reinsenauer et al. (1973) as being the critical level between an excessive and sufficient soil boron level for alfalfa. These five sites were all located along Indian and Antelope Creeks, both of which have historically had high boron levels. In two of these fields toxicity symptoms were observed in some of the alfalfa plants, one field along Indian Creek and one in the Antelope creek area.

As could be expected, it was found that the coarser textured soils contained a lower amount of soluble boron than the more clayey soils. Also, the soils with the highest boron content were the heavy soils irrigated with waters containing high levels of boron.

Treatment effect. At the Evans farm in Millville, Cache Co., 2.8 kg of boron per hectare was applied to the plots. Table 4 shows that there was an increase of 0.23 mg/kg available soil boron with the addition of Solubor amounting to a 24.24% increase over the non treated strips. Table 4 also presents the t - test values for this treatment showing that there was a significant difference between available soil boron of the untreated strip and the strip where boron was applied.

Table 4. Means and t-test for available soil boron on treated and non-treated strips at Cache County plot.

	Check Strip -B	Treated Strip +B
mean available soil level (mg/kg)	0.99	1.23

t(tabular) = 1.86
t(.05,6) = 2.447 *

* significant at 5% level

Plant Boron Results

Plot averages. The range of plant boron content is shown in Table 3 . The averages ranged from 57.5 to 254 mg/kg boron in dried plant tissues. None of the plants showed any boron deficiency symptoms in the field. Also, foliar analysis did not reflect boron deficiency which, according to Gupta (1979) and James and Weaver (1964), is below 20 mg/kg boron in alfalfa dry matter. Most of the plants sampled appeared to be in the upper sufficiency levels with respect to their boron content (Meyer and Martin, 1976; Neubert et al., 1970). Areas with plant analysis averaging in the toxic range, above 200 mg/kg were found in Duchesne County along Indian and Antelope Creeks. Only two of the fields sampled along these 2 waterways contained plant tissue samples with boron contents over 200 mg/kg. Table 3 shows these 2 locations (sites 9a and 12a). The irrigation waters for these sites was above the 4 mg/kg critical limit for boron (Wilcox, 1948b) and extractable soil boron above 5 mg/kg, listed by Reisenauer et al. (1973), as being the maximum upper safe limit for soil boron.

Variety effect. In Morgan and Tooele Counties twelve alfalfa varieties were sampled for boron uptake. Figure 2 and Table 5 present the results for Morgan County. As indicated, the variety Anchor had the highest average boron content of the twelve varieties with 67.25 mg/kg while variety AS-49R had the lowest. There were three results in the origional data which appeared questionable due to being much lower than the other results. The Q-test, (Dixon, 1951), was applied and it was determined that these three results could be deleted with a 90% confidence level. These three data points were deleted and replaced using a missing data procedure (Dowdy and Wearden, 1983). The analysis of variance was run with the three erroneous values omitted and a significant difference was found between the varieties and the plant boron content at the 5% level. Table 6 presents the analysis of variance for the Morgan County plots.

In order to determine which varieties were significantly different in boron content, a multiple comparison procedure was performed. Table 7 presents Fischers Least Significant Difference means comparison (LSD) which was chosen because it is one of the more liberal tests (Dowdy and Wearden, 1983) and, therefore, more likely to identify varieties which are different in boron content. Table 8 shows the data for plant boron content for Tooele County with the same twelve alfalfa varieties tested in Morgan County. At the Tooele Co. site, the variety Washoe had the highest average plant boron content at 77.5 mg/kg while variety WL-309 had the lowest at 57.75 mg/kg. Table 9 presents the analysis of variance for the Tooele County plot results and shows that there was no difference amoung varieties at the Tooele location.

The data from the two locations was pooled and a significant difference between locations and alfalfa varieties for boron content of plant tissue was found. The results and overall means are found in Figure 3 and Table 10 with the analysis of varience in Table 11. Table 12 presents the LSD mean comparisons indicating the

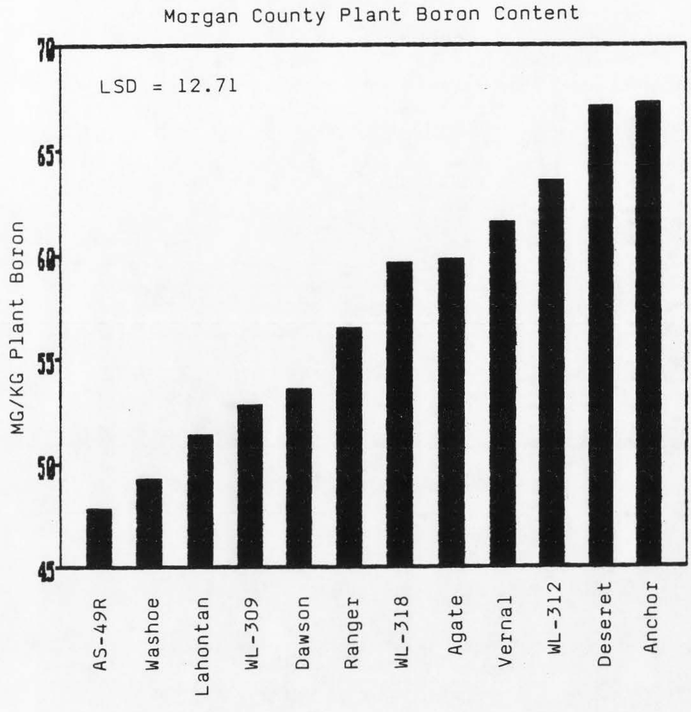

Figure 2. Morgan County alfalfa variety differences.

Table 5. Boron composition of 12 alfalfa varieties at Morgan County.

Variety	Replication 1	2	3	4	Mean	S.D.
	-------mg/kg-------				mg/kg	
WL-309	52	48	62	49	52.75	6.4
WL-312	56	64(a)	66	68	63.50	5.26
WL-318	59	68(a)	53	58	59.50	6.24
Ranger	56	57	72	41	56.50	12.66
Agate	56	58	63	62	59.75	3.30
Vernal	60(a)	63	61	62	61.50	1.29
Lahontan	58	43	45	59	51.25	8.42
AS-49R	32	57	50	52	47.75	10.90
Dawson	59	52	48	55	53.50	4.65
Anchor	63	70	75	61	67.25	6.45
Deseret	64	58	66	80	67.00	9.31
Washoe	45	41	50	61	49.25	8.66

(a) Location of results which were originally deleted and replaced

Table 6. Analysis of variance for Morgan County results.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F	F (.05)
Variety	11	1952.42	177.49	2.75*	2.126
Block	3	148.75	49.58	0.77	
Residual	30(a)	1936.75	64.56		
Total	44(a)	4037.92			

* Significant at 5% level

(a) degree of freedom reduced by 3 due to replacing 3 missing data points (Dowdy and Wearden, 1983)

Table 7. Fischers LSD means differences in alfalfa varieties for Morgan County.

Variety Number (a)

	2	3	4	5	6	7	8	9	10	11	12
1	1.5	3.5	5.0	5.7	8.7	11.7	12.0	13.7*	15.7*	19.2*	19.5*
2		2.0	3.5	4.2	7.2	10.2	10.5	12.2*	14.2*	17.7*	18.0*
3			1.5	2.2	5.2	8.2	8.5	10.2	12.2*	15.7*	16.0*
4				0.7	3.7	6.7	7.0	8.7	10.7	14.2*	14.5*
5					3.0	6.0	6.2	8.0	10.0	13.5*	13.7*
6						3.0	3.2	5.0	7.0	10.5	10.7
7							0.2	2.0	4.0	7.5	7.7
8								1.7	3.7	7.2	7.5
9									2.0	5.5	5.7
10										3.5	3.9
11											0.2

LSD value = 12.71
* significant at the 5% level.

(a) Alfalfa varieties for Morgan County in the above Table are represented by numbers 1 - 12. The numbers and varieties are as follows along with the appropriate means used to calculate the differences.

Variety	Mean mg/kg
1. AS-49R	47.75
2. Washoe	49.25
3. Lahontan	51.25
4. WL-309	52.75
5. Dawson	53.50
6. Ranger	56.50
7. WL-318	59.50
8. Agate	59.75
9. Vernal	61.50
10. WL-312	63.50
11. Deseret	67.00
12. Anchor	67.25

Table 8. Boron composition and averages of 12 alfalfa varieties at Tooele County.

Variety	Replication 1	2	3	4	Mean	S.D.
	-----mg/kg-----				mg/kg	
WL-309	51	63	58	59	57.75	4.99
WL-312	75	71	70	61	69.25	5.91
WL-318	58	56	59	70	60.50	6.29
Ranger	65	70	61	63	64.75	3.86
Agate	73	100	58	64	73.75	18.55
Vernal	65	70	69	70	68.50	2.38
Lahontan	80	63	76	72(a)	72.75	7.27
AS-49R	70	65	65	48	62.00	9.36
Dawson	65	58	61	65	62.25	3.40
Anchor	79	58	62	63	65.50	9.26
Deseret	79	88	53	68	72.00	15.08
Washoe	90	63	65	92	77.50	15.63

(a) Location of replaced missing data

Table 9. Analysis of variance for Tooele County plots.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F	F (.05)
Variety	11	1600.23	145.48	1.49NS	2.126
Block	3	401.40	133.80	1.41	
Residual	32(a)	3134.85	97.96		
Total	46(a)	5136.48			

NS= not significant

(a) Degree of freedom lowered by 1 due to replacing 1 missing data point (Dowdy and Wearden, 1983)

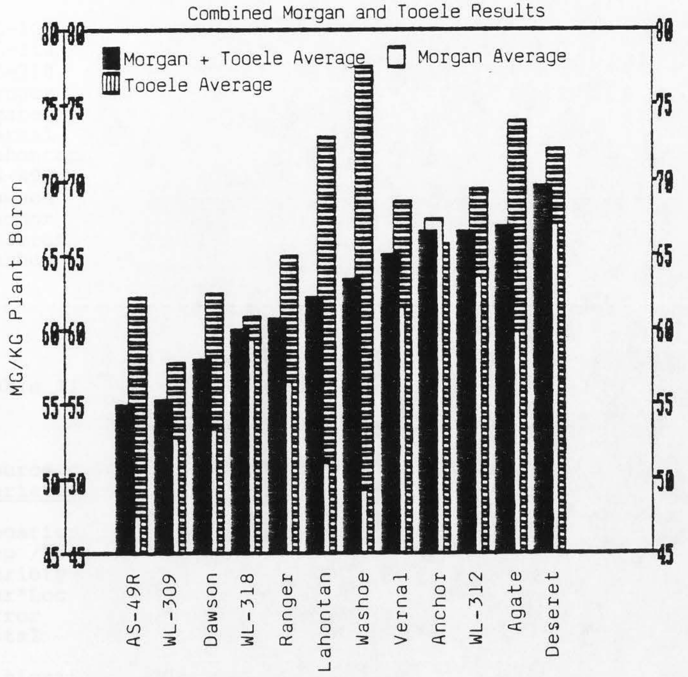

Figure 3. Boron content of plant tissue for Morgan and Tooele County along with means.

Table 10. Boron composition of alfalfa varieties from combined Morgan and Tooele County plots.

Variety	Morgan	Tooele	Overall Mean
	---------------mg/kg---------------		
WL-309	52.75	57.75	55.25
WL-312	63.50	69.25	66.38
WL-318	59.50	60.75	60.13
Ranger	56.50	64.75	60.63
Agate	59.75	73.75	66.75
Vernal	61.50	68.50	65.00
Lahontan	51.25	72.75	62.00
AS-49R	47.75	62.00	54.88
Dawson	53.50	62.25	57.88
Anchor	67.25	65.50	66.38
Deseret	67.00	72.00	69.50
Washoe	49.25	77.50	63.38

Table 11. Analysis of variance for combined data from Morgan and Tooele Counties.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F	F (.05)
Location	1	2291.26	2291.26	29.82*	4.00
Rep /Loc	6	550.15	91.69	1.19NS	2.3
Variety	11	1962.53	178.41	2.32*	1.9
Var*Loc	11	1590.11	144.56	1.88NS	1.9
error	66	5071.60	76.84		
Total	95	11465.66			

* significant at 5% level

NS= not significant

Table 12. LSD means difference comparison for combined Morgan and Tooele County plant boron content.

	Variety Numbers (a)										
	2	3	4	5	6	7	8	9	10	11	12
1	0.4	3.0	5.2	5.7	7.1	8.5	10.1*	11.5*	11.5*	11.9*	14.6*
2		2.6	4.9	5.4	6.7	8.1	9.7*	11.1*	11.1*	11.5*	14.2*
3			2.2	2.7	4.1	5.5	7.1	8.5	8.5	8.9*	11.6*
4				0.5	1.9	3.2	4.9	6.2	6.2	6.6	9.4*
5					1.4	2.7	4.4	5.7	5.7	6.1	8.9*
6						1.4	3.0	4.4	4.4	4.7	7.5
7							1.6	3.0	3.0	3.4	6.1
8								1.4	1.4	1.7	4.5
9									0.0	0.4	3.1
10										0.4	3.1
11											2.7

Fischers LSD value = 8.7509

* significant at 5% level

(a) Alfalfa varietys for both Morgan and Tooele Counties are represented by variety numbers. The variety number and the variety are listed below with the means used for the differences in the LSD table.

Variety	Mean mg/kg
1. AS-49R	54.88
2. WL-309	55.25
3. Dawson	57.88
4. WL-318	60.13
5. Ranger	60.63
6. Lahontan	62.00
7. Washoe	63.38
8. Vernal	65.00
9. Anchor	66.38
10. WL-312	66.38
11. Agate	66.75
12. Deseret	69.50

significance of varietal boron contents. Variety Deseret contained the highest average boron content at 69.5 mg/kg while variety AS-49R contained the lowest at 54.88 mg/kg. The differences may be important for selection of alfalfa adaptable to either high or low boron levels in the soil or irrigation water.

Treatment effect. The Evans farm was the only location where boron was applied to soils and plants as a treatment. Table 13 presents the results of plant tissue analysis of the non-treated first crop which averaged 57 mg/kg boron and the non-treated second crop which averaged 57.47 mg/kg. The alfalfa boron content of the boron - treated second crop averaged 68.43 mg/kg. Since there was no difference between the first and second crop boron content of the check strips as part (a) in Table 13 shows, a t-test was run only for the second crop treated and non-treated plots. There was a significant treatment effect as can be seen in part (b) of Table 13. By increasing the average available soil boron content by 24.24% in this field (see table 4) with the application of Solubor, the average plant boron content was increased by 19.17%.

Irrigation Water Boron Content

Table 14 presents the results of the irrigation water boron analyses. It can be seen that there was a large variation throughout the season with respect to the boron content of these waters. This is probably due to a dilution

Table 13. Mean plant boron tissue content from check strip and treated strip and t-test for differences between strips at Cache County site.

	Mean mg/kg	S.D.
1st cutting -B	57.2	10.82
2nd cutting -B	57.5	7.53
2nd cutting +B	68.1	8.20

a) t-test 1st cutting vs. 2nd cutting, check plots

t(.05, 41) = 0.11 NS
t(tabular) = 2.021

b) T-test on 2nd cutting check vs. treated strip

t(.05, 41) = 4.38*
t(tabular) = 2.201

NS= not significant

* significant at 5% level

Table 14. Antelope and Indian Creek water boron content changes during summer of 1984.

Site # + Location (a)	Sampling Date				
	6-8-84	7-20-84	8-23-84	9-28-84	Mean
	Boron Content mg/kg				
8. Indian Creek	4.65	3.96	1.12	4.32	3.49
10. Indian Creek	6.55	7.70	6.74	3.01	6.00
13. Antelope Creek	2.82	5.00	2.54	1.30	2.92
Strawberry River at Duchesne	0.25	0.18	0.17	0.15	0.19

(a) Site and location may be found in Table 1 and Figure 1.

effect caused by the rate of water flow, as affected by the weather and irrigation water usage rates.

Tooele County plot was the only other location needing supplementary water data for this study because no prior data could be found. The irrigation water well was sampled. This well water and all other irrigation waters, except those from Indian and Antelope Creeks, were within the limits for a normal boron content according to Wilcox (1948b). Apparently, only those waters in Utah which originate in or flow through the same geographical area as Antelope and Indian Creeks, or which are industrial or agricultural waste waters contain high boron levels (Hanks et al.,1985).

Precision of Analysis

In order to determine the precision of analysis for soil and plant boron content, random samples were analyzed repeatedly. The coefficient of variation (CV) for these analyses is given in Tables 15 and 16 for plant and soils respectively. The CV for plants were somewhat higher than for the soils but all the CVs were fairly low indicating satisfactory laboratory precision.

Regression Analysis

The predictability of the boron content of plant tissue from the irrigation water and soil boron data was tested using multiple linear regression. The derived model equation for predicting the plant boron content from the

Table 15. Coefficient of variation for plant tissue boron content analysis.

Site # + Location	Mean mg/kg	S.Dev.	CV(%)
11. Duchesne County	133.20	13.97	10.49
12. Duchesne County	141.00	12.29	8.72
13. Duchesne County	127.33	18.77	14.74
17. Iron County	82.00	10.15	12.38

(Site location and description are found in Table 1 and Figure 1.)

Table 16. Coefficient of variation for available soil boron analysis.

Site # + Location	Mean mg/kg	S.Dev.	CV(%)
2. Cache County (+B)	1.25	0.06	4.80
9. Duchesne County	11.31	0.29	2.56
14. Duchesne County	7.94	0.46	5.79
18. Grand County	0.00	0.00	1.00

(Site location and description are found in Table 1 and Figure 1.)

soil and water boron levels was $Y = 63.32 + 0.43 X_1 + 7.42 X_2$ ($R^2 = 0.82$) where X_1 was the soil test boron and X_2 was the irrigation water boron content , both in SI units. An analysis of variance was run to determine if $R^2 = 0.82$ was significant. Table 17 shows the regression equation was significant. When the source of variation for the regression term in the analysis of variance was broken down into its components of soil and water, the soil term was found to be the main source of significance.

Table 17. Analysis of variance for multiple regression equation.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F	F (.05)
Regression	2	15278.07	7639.04	35.01*	3.68
Soil	1	14857.19	14857.19	67.95*	4.54
Water	1	414.30	414.30	1.89NS	4.54
Deviations	15	3273.07	218.20		
Total	17	18551.14			

* significant at 5 % level

NS = not significant

An interaction term for soil and water was added to the equation to determine if an improvement of predictability could be gained. The R^2 value stayed at 0.82 but the estimated predictibility of boron in the plant tissue from the actual measured levels went from 14.78 mg/kg to 15.23 mg/kg, or a loss of predictibility of about 0.5 mg/kg when the interaction term was included, hence the interaction term was removed from the prediction equation.

A correlation between the soil and water boron content was run to determine the affect of one variable on the other. It was found that the soil and water boron content are so inter-related that only one term is needed. The t-value for the soil was 1.714 and for the water boron level was 0.049. The tabular t-value at 5% was 2.131. This more or less shows that both variables are predicting the same thing and that either one is useful by its self but that nothing is gained by combining the available soil boron and irrigation water boron level terms. Since both the water and soil boron levels may be used alone to predict the plant boron content, 2 linear regressions were evaluated to determine which gave the better prediction of plant boron.

The calculated prediction equation for plant boron using the irrigation water boron as the variable was $Y = 69.91 + 13.64X$ ($R^2 = 0.79$). The estimated plant boron content using this equation was within 15.66 mg/kg of the actual measured values for plant boron. Table 18 presents the analysis of variance.

The prediction equation for plant boron using the soil test boron level was $Y = 63.16 + 7.66X$ ($R^2 = 0.82$). This equation gives an estimated plant boron content within 14.31 mg/kg of the actual measured levels. Table 19 containes the analysis of variance for this regression.

Table 18. Analysis of variance for soil and plant linear regression model.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F	F (.05)
Model	1	15270.97	15270.97	74.49**	4.49
Error	16	3280.17	205.01		
Total	17	18551.14			

** Significant at 1% level

The predictability of the soil test boron or the boron content of the irrigation water are very close to each other, but it appears that the soil test boron gives about 1.5 mg/kg better predictability than the irrigation water boron level, and has a slightly lower MSE term in the analysis of variance. Because of these 2 reasons the soil test boron levels should be the prefered variable over the irrigation water boron levels for the prediction of plant boron content when a choice between the two variables is available.

Table 19. Analysis of variance for water and plant linear regression model.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F	F (.05)
Model	1	14629.38	14629.38	59.68**	4.49
Error	16	3921.76	245.11		
Total	17	18551.14			

** Significant at 1% level

SUMMARY AND CONCLUSIONS

The primary purpose of this study was to assess the boron status of typical alfalfa crops and soils in Utah, to determine if there are any problems of deficiency or toxicity due to the boron content. A second purpose was to evaluate the affect of irrigation water with respect to the boron status in these same soils and crops, and to determine normal boron contents of several alfalfa varieties.

Various locations were selected throughout the state of Utah in order to gain an overall perspective of the boron fertility levels in soils and plant uptake. There were wide ranges in the soil types, climatic conditions, plot elevations, and managment practices on the fields chosen. However, all the selected sites were irrigated. Twelve alfalfa varieties in Morgan and Tooele Counties were analyzed to compare the total plant boron content among varieties. Boron fertilizer in the form of Solubor was added at the Cache County location on a strip of the field to determine the affect of boron fertilization on the plant and soil boron content. The plant and soil samples at all locations were randomly collected within each field to get a representative sample for boron analysis.

The following results were obtained from this study:

1. In fields where the boron content of the irrigation

water was within the guidelines reported by Wilcox (1948b), no toxicity problems were found in soils or plants.

2. Boron deficiency symptoms were not observed at any of the locations or in any plant tissue samples.

3. Alfalfa variety Anchor had the highest average concentration of boron in the plant tissue at Morgan County and variety AS-49R had the lowest boron level. In Tooele County variety Washoe had the highest plant boron while variety WL-309 contained the lowest average boron level.

When the alfalfa boron content of both Morgan and Tooele Counties was pooled a significant location and variety difference was found. Varieties AS-49R and WL-309 contained the lowest average boron for both locations while alfalfa varieties Deseret , Agate and WL-312 were the highest boron containing varieties. The differences could be due to different growth patterns or physical characteristics between the varieties but these were not specifically evaluated. Since no correlation was made between yield and the boron content of the alfalfa varieties, no conclusion could be made as to whether one variety might perform better than another when grown under high or low boron soil conditions.

4. Boron toxicity symptoms were only seen in fields irrigated with water from Indian or Antelope Creek in Duchesne County where the boron levels in the irrigation water, during certain periods of the growing season, can be

well over the critical levels reported by Wilcox (1948b). Plants showing toxicity symptoms were analyzed and found to contain boron in excess of the level reported as being toxic by Meyer and Martin (1976) and Neubert et al. (1970).

5. Hot water extractable soil boron approached toxic concentrations only in the fields irrigated with high boron containing waters from Antelope or Indian Creeks.

6. Available soil boron was found to be below the limiting level as reported by James and Weaver (1964) and Stinson (1953) only in the Grand County location. However, the plant tissue samples contained normal boron levels as reported by Gupta (1979) and Stinson (1953). The plant boron at this location appears to be supplied by the irrigation water.

7. Addition of the boron fertilizer "Solubor" in Cache County at a rate of about 2.8 kg boron per hectare significantly increased the plant tissue boron content 19.17% and the available soil boron content by 24.24%.

8. No differences in the lab analysis results were found between Pyrex and Vycor (low boron) glassware.

9. A significant prediction equation of $Y = 63.32 + 7.42\ X_1 + 0.43\ X_2$ ($R^2 = 0.82$) for plant boron content was derived from the irrigation water and soil test boron levels; where X_1 is the soil test boron level in mg/kg and X_2 the irrigation water boron content in mg/l. The soil test boron level and the irrigation water boron levels were found to be highly correlated with each other, therefore,

the multiple regression equation with both variables is not needed. A simple linear equation for either the soil or irrigation water boron level will do just as well for predicting plant tissue boron contents.

When testing the seperate linear regression models for both the irrigation water and soil test boron contents, each equation was found to be significant and of about equivalent value for predicting plant boron content. The prediction equation for the irrigaiton water boron content is $Y = 69.91 + 13.64X$ ($R^2 = 0.79$) has an estimated plant boron predictability of + or - 15.66 mg/kg from the actual measured values. The soil test prediction equation of $Y = 63.15 + 7.66X$ ($R^2 = 0.82$) was found to be a little better in predicting plant boron content with a predictability of + or - 14.32 mg/kg from the actual measured values and a slightly higher R^2 value.

RECOMMENDATIONS

Though the two boron prediction equations evaluated were significant and of an approximate equivalent value, their validity needs to be further evaluated over a wider area and under varying conditions throughout the state.

The differences among and variation in boron content of alfalfa varieties should be further studied to determine if other soil, water, or environmental conditions have any significant impact on the boron content of the alfalfa varieties. The variety yield differences also need to be evaluated under field conditions of varying levels of available boron to evaluate their yield performance under a range of different available boron levels.

At the Grand County site at Moab, where the irrigation water and soil contain low boron levels, or other similar locations, the boron status of the plant material should be closely monitored. This is due to a greater possibility of a boron deficiency arising here than in other regions where the available boron is not at such a low level. If boron deficiencies do arise, they can be easily solved by the application of boron containing fertilizers.

In the Uintah Basin where high levels of boron occur in the irrigation waters and associated soils, the yield of irrigated alfalfa has probably been reduced. A reduction in yield, however, has not been substantiated and more research is needed to verify if any crop reduction has occured, along with the possibility of a method to reclaim these soils, especially in the Duchesne and Myton areas of Duchesne County where most of these high level boron waters have been used.

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Figure 2. Morgan County alfalfa variety differences.