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Boron Requirement of 'Sharwil' Avocado Trees

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Abstract. Misshapen fruits of avocado [*Persea americana* Mill. (*P. gratissima* C.F. Gaertn.) 'Sharwil'] were observed during the 1989-90 season in Kona, Hawaii and hypothesized to be due to B deficiency. To determine the B requirement of 'Sharwil' avocados, two greenhouse experiments and a four-year, on-farm field trial were conducted. In a greenhouse soil study, seven B treatments (0, 3.7, 11, 22, 44, 89, and 178 mg B kg^{-1} soil fines) were applied to one-year-old grafted 'Sharwil' avocado trees grown for 13 weeks in a Tropofolist soil. Adequate foliar B concentrations in young, 'Sharwil' avocados based on dry weight and area of new leaves ranged from 37($\pm$3) to 65($\pm$4) and from 31($\pm$10) to 78($\pm$13) mg kg^{-1} (dry weight basis), respectively (means are followed by standard errors of the mean in parentheses). In a greenhouse hydroponics study, six-month-old grafted 'Sharwil' avocado trees were supplied with 4 levels of B (0, 1, 10, and 100 μM). At 11 months after B treatment initiation, leaves with deformed margins and a 'shot-hole' appearance were first observed at a solution level of 0 μM B. Foliar B concentrations at 14 months after B treatment initiation that were associated with 12 to 14% incidence of deformed leaves ranged from 9.8 to 13.5 mg kg^{-1} (dry weight basis). In a field trial, three N rates (225, 450, and 675 g $tree^{-1}$) as urea and two B rates (0 and 69 g $tree^{-1}$) as Solubor were applied annually in a factorial combination of treatments to single tree plots on six to eight farms. In addition, a high B rate of 138 g $tree^{-1}$ was applied annually to the middle N treatment rate. Leaves were sampled during the fall from the summer vegetative flush. Adequate foliar B concentrations based on Grade 1 and total fruit yields ranged from 40 to 67 mg kg^{-1} and from 42 to 70

mg kg^{-1} (dry weight basis), respectively. Thus, adequate foliar B concentrations in 'Sharwil' avocados ranged from 40 to 70 mg kg^{-1} based on either vegetative growth or fruit yield. Although 'Sharwil' avocados were reported to be especially susceptible to B deficiency, foliar B concentrations required for adequate growth are similar to those required by other cultivars.

In Hawaii, the principal avocado cultivar is 'Sharwil' (Bittenbender et al., 1989), a cross between Mexican and Guatemalan races. Avocado production in this state is centered in the district of Kona on the Island of Hawaii, typically on Tropofolist (Histosol) organic soils. These soils are unique, because they are composed of a thin organic surface layer underlain by lava (USDA- SCS, 1973).

Misshapen fruits of 'Sharwil' with a lop-sided appearance were observed during the 1989-90 season (Bittenbender, 1990). Most of these fruit deformities appeared similar to the sickle-shaped fruit with navel-like lesions caused by B deficiency (Broadley et al., 1991, Piccone and Whiley, 1987, and Whiley et al., 1996). It was hypothesized that B deficiency was the major cause of these misshapen fruits, because the foliar B concentrations at over 10 farms in the Kona area during the Fall of 1989 averaged 20 mg kg^{-1}, which was much below recommended levels (Coetzer et al., 1993; Embleton and Jones, 1966; Piccone and Whiley, 1987; Whiley et al., 1996).

The primary function of B in higher plants is still uncertain, but proposed roles involve synthesis and stabilization of cell walls as well as plasma membranes, transport of sugars, auxin metabolism, and lignin biosynthesis (Marschner, 1995). In particular, B is required for pollen viability and pollen tube growth (Marschner, 1995). Robbertse et al. (1990) showed that optimal pollen tube growth of 'Hass' avocados was found at a B concentration in flowers ranging from 50 to 75 mg kg^{-1}. Smith et al. (1997) demonstrated that germination of pollen from B-deficient 'Hass' avocado trees was 16-fold less than that from B-fertilized trees. Also, panicles of 'Hass' trees with a marginal B status that were sprayed with B at the start of anthesis showed a 42% increase in initial fruit set compared to controls, although no increase in final fruit yield occurred (Smith et al., 1997).

Embleton and Jones (1966) reported that adequate foliar B concentration ranged between 50 to 100 mg kg^{-1} for avocados, but they stated that additional data was needed to support this range. In Australia, Whiley et al. (1996) found that the optimal foliar B concentration ranged from 40 to 60 mg B kg^{-1} for mature summer flush leaves of avocado prior to inflorescence development. In South Africa, Coetzer et al. (1993) reported that the optimal B concentration in leaves below the axillary buds ranged from 60 to 80 mg kg^{-1}. Genotypic differences have been found in responses of avocados to B, with the cultivar Sharwil reported to be especially susceptible to B deficiency (Piccone and Whiley, 1987; Whiley et al., 1996). However, there was no information on whether B requirements of 'Sharwil' avocados differed from those of other cultivars used to develop adequate ranges of foliar B concentrations.

Objectives of the soil study conducted in the greenhouse were: a) to determine the effect of B fertilization on the vegetative growth of young 'Sharwil' avocado trees; and b) to determine the range of B concentrations in leaves and soil fines that are associated with optimum vegetative growth. Objectives of the hydroponics study were: a) to determine symptoms of B deficiency and toxicity on young 'Sharwil' avocados; and b) to determine foliar B levels associated with such symptoms. Finally, one objective of a four-year, on-farm fertilizer trial in Kona, Hawaii was to determine the adequate range of foliar B levels associated with high yields and good fruit quality.

Materials and Methods

Soil study. The two greenhouse experiments were conducted at a greenhouse in Waiakea, Hawaii (19° 39' N, 155° 05' W). Avocado seeds of 'MAL-2-1' (from University of Hawaii's germplasm collection) were germinated in February 1991 in perlite under 50% shade and intermittent mist. They were transplanted to black 20 x 40 cm polyethylene pots containing 13.1 kg (oven dry weight) of rocks and soil fines from the Kaimu series (isohyperthermic, euic, Typic Tropofolist). Components of this medium were (on a dry weight basis): rocks larger than 25 mm in diameter, 20%; rocks between 25 and 6 mm, 38%; rocks between 6 and 2 mm in diameter, 24%; and soil fines less than 2 mm in diameter, 17%. The two larger rock fractions were mixed and placed at the bottom of the pot. The smallest rock fraction and the soil fines were mixed and placed over the larger rock fractions. The proportions of rocks and soil fines in this medium, and their distribution in the pot were based on measurements and observations from a Kaimu series soil profile which was located in a 'Sharwil' orchard. The soil and rock fractions were obtained from Waiea, Hawaii (19^{o} 22' N, 155^{o} 52'W).

In the unamended soil fines, total N was determined by a micro-Kjehldal method (Isaac and Johnson, 1976), organic carbon was measured by the method of Heans (1984), available P was analyzed by the modified Truog method (Ayers and Hagihara, 1952), and exchangeable cations were determined by the ammonium acetate (pH 7) method (Thomas, 1982). Hot water extractable B levels in the unamended soil fines were measured using the method of Mahler et al. (1984) and Wolf (1974). Analyses were conducted by the Agricultural Diagnostic Service Center of the University of Hawaii - Manoa. Analyses of the unamended soil fines were (on an oven-dried soil basis): pH, 5.8; total N, 11.4 g kg^{-1}; organic carbon, 125 g kg^{-1}; dilute sulfuric acid-extractable P (Truog-P), 150 mg kg^{-1}. Exchangeable cations were, in mg kg^{-1} soil fines: K, 310; Ca, 3700; and Mg, 450.

Two and 11.5 months after seed germination, 50 g of Osmocote 13.5-13.5-13.5 (Sierra Chemical Co., Milpitas, CA) were broadcast over the soil surface of each pot. Six months after seed germination, 'Sharwil' scionwood was grafted onto the 'MAL-2-1' seedling rootstock.

Six months after grafting, trees were randomized and blocks established on the basis of initial plant size and position on the greenhouse bench. Seven B treatments (0, 8, 24, 48, 95, 191, and 381 mg B pot^{-1}) were applied by pipetting 50 mL of appropriate concentrations of H_3BO_3 onto the soil surface (Table 1). There were a total of 30 pots, with four replicates of treatments 0 to 4 and five replicates of treatments 5 and 6 (Table 1). Trees were irrigated with 500 mL day^{-1} (or 1.6 cm day^{-1}) of tap water that contained non-detectable concentrations of B (<0.01 mg B L^{-1}) as measured by the azomethine-H method (Wolf, 1974). Pesticides used for mite control included malathion (Malathion

25W, FMC Corporation, Philadelphia, PA) applied immediately prior to B treatment initiation plus four weeks later, and dienochlor (Pentac Aquaflow Miticide, Sandoz Crop Protection, Des Plaines, IL) sprayed eight weeks after application of B treatments.

Two weeks prior to the application of B treatments, approximately 12 leaves per tree were sampled from the youngest fully expanded flush of leaves. Then, nine weeks after B application, approximately 7 leaves per tree were sampled from the youngest fully expanded flush of leaves. Leaves were rinsed three times in deionized water, blotted to remove excess moisture, dried at 75°C to constant weight, and analyzed for B by the azomethine-H method (Wolf, 1974).

The experiment was terminated 13 weeks after B treatment initiation. Leaves were separated into new leaves (those that developed after B treatment initiation) and old leaves (those that developed before application of B treatments). Roots were washed free of media and separated into fine roots and the tap root. Leaf areas and fine root lengths were determined using a digital image analysis system (Decagon Devices, Pullman, WA). Fresh weights of these plant parts were measured, then dry weights were determined after drying at 75°C.

Treatment effects were evaluated by analysis of variance (ANOVA) (SAS, 1982). Linear B (B), block, and quadratic B (B^2) effects were calculated. A probability level of 0.05 or less was considered to be statistically significant. Dry weight and area of new leaves were regressed against foliar B concentrations, using linear and several non-linear regression models (SAS, 1982). For non-linear regression models, the coefficient of determination (r^2) was calculated to be 1 - (Residual sum of squares/Corrected total sum of squares). Criteria in determining the regression model with the best fit for each relationship were the highest r^2 and adequacy of fit as judged from plots of residual versus predicted values. Standard errors for the optimal range of foliar B concentrations associated with 90% of maximum leaf areas or leaf dry weights were calculated using the delta method (Bishop et al., 1975).

To determine B sorption of this soil, B as boric acid (H_3BO_3) was added to duplicate 100-g soil samples that were air-dried and sieved (< 2 mm). Rates of B applied in mg B kg^{-1} soil fines were: 0.0, 0.5, 1.0, 1.5, 2.0, 5.0, 10, 20, 50, 100, and 200. The soil fines were brought up to 15% water content and incubated in plastic bags for 18 days and analyzed for hot water extractable B (Mahler et al., 1984; Wolf, 1974).

Hydroponics Study. Avocado seeds from 'Itzamna' were germinated in June 1991 in a perlite:vermiculite mix (1:1, v:v). Seedlings were transplanted to black, 20 x 40 cm polyethylene pots containing rockwool and fertigated with a complete nutrient solution (Tomato 4-18-38, Chem-Gro, Colorado Springs, CO). Macronutrient concentrations were, in m*M*: NO_3-N, 1.84; P, 0.33; K, 1.04; Ca, 0.73; Mg, 0.3; and S, 0.3. Micronutrient concentrations were, in μM: Fe as FeEDTA, 10; Mn, 5, Zn, 1; Cu, 1; Mo, 0.1; and B, 24. Submersible pumps were placed in 100-L plastic containers with nutrient solution to fertigate the seedlings at approximately 0.5 L per day. As the seedlings increased in size, fertigation rates were gradually increased to approximately 2.5 L per day.

'Sharwil' scionwood was grafted onto rootstock six months after the start of germination. Five months after grafting, the 'Sharwil' trees were pruned. At six months after grafting, B treatments were initiated. Nutrient solutions were made from reagent grade chemicals with the same concentrations as those used earlier, with B levels of 0, 1, 10, and 100 μM. Trees were fertigated at the rate of approximately 2.5 L per day. The experiment followed a randomized complete block design and each treatment was replicated six times.

After two months of B treatments, leaves and stems that were produced after the start of the experiment were sampled. Leaves were dried at 70°C and analyzed for B concentration as discussed previously.

To control mites, dienochlor (Pentac Aquaflow Miticide, Sandoz Crop Protection, Des Plaines, IL) was sprayed at five and seven months after B treatment initiation. To control scales, malathion (Malathion 25W, FMC Corporation, Philadelphia, PA) was applied at 12 months after start of treatments.

At 14 months after treatment initiation, leaves and stems were separated into new growth (since the last sampling) and old growth (present before the last sampling above the graft union). Leaf areas, and fresh and dry weights of leaves and stems were determined. Leaf samples were analyzed for B as described in the previous study.

On-Farm Field Trial. Experimental methods were detailed previously in Miyasaka et al. (1992). To summarize, eight farmers agreed initially to participate in this fertilizer trial, but only six farmers continued to participate through all four years of the study. Of these participating farms, only two used irrigation and the rest were dependent on rainfall for moisture. At treatment initiation, estimated ages of the trees from grafting ranged from 3.5 to 9 years. Three N and two B rates were applied in a factorial combination of treatments. The experimental design was a randomized complete block, with each farm equivalent to a replicate. Plots consisted of single trees, which were planted at a spacing of approximately 120 trees ha^{-1}.

In April and June 1990, three rates of N (90, 180, and 270 g $tree^{-1}$ $application^{-1}$) as urea were broadcast under the tree canopy. The middle N fertilizer treatment is the most commonly applied N rate for avocados in Kona, Hawaii (Mills-Packo et al., 1990). This N rate was halved for the low N treatment, to determine whether avocado trees were being over-fertilized. The high N rate was 50% greater than the middle N treatment, to determine whether avocado yields could be improved by higher N fertilization. In October 1990, N (45, 90, and 135 g $tree^{-1}$) as urea was broadcast, based on the recommendation by Piccone and Whiley (1987) to reduce N fertilization during the fall months. During subsequent years, the same rates of N were applied in April, July, and October at annual N application rates of 225, 450, and 675 g $tree^{-1}$.

Two rates of B (0 and 23 g $tree^{-1}$ $application^{-1}$) as Solubor were applied as a spray to the ground under the tree canopy in February 1990, and these treatments were repeated in August and December 1990. The B fertilization rate was based on recommendations by Piccone and Whiley (1987), using leaf B analyses and canopy diameters. During subsequent years, the same B rates were applied in April, July, and October at annual B application rates of 0 and 69 g $tree^{-1}$. In addition, a high B rate of 46 g $tree^{-1}$ $application^{-1}$ was applied only at the middle rate of N, to determine the effect of doubling the recommended B rate. The annual B application rate for the high B treatment was 138 g $tree^{-1}$.

In addition to N and B fertilizers, potassium (K) and phosphorus (P) were applied to all trees. In April and June 1990, K as sulfate of potash was broadcast under all experimental trees at 240 g $tree^{-1}$ $application^{-1}$. In October 1990, K at 120 g $tree^{-1}$ was broadcast, based on the recommendation by Piccone and Whiley (1987) to reduce K fertilization during the fall. Phosphorus as treble superphosphate was broadcast under all experimental trees at 30 g $tree^{-1}$ $application^{-1}$ in April, June, and October 1990. In subsequent years, the same rates of K and P were applied in April, July, and October at annual rates of 600 g K $tree^{-1}$ and 90 g P $tree^{-1}$.

Leaf samples from non-flowering, non-bearing, and non-flushing terminals of the summer vegetative flush were taken in October of each year, when leaves were 3 to 4 months-old (prior to October fertilization). Leaf samples were analyzed for B as described earlier.

Individual tree yields were determined from October through March of each year when fruits were mature. Fruits were separated into the following categories: grade 1 (unblemished), off grades due to deformities, off grades due to Mexican leaf roller (Amorbia emigratelia Busck) damage, and off grades due to other factors. Numbers of fruits as well as fresh weights were recorded.

Due to the alternate-bearing nature of avocados, harvest data were summed over 2-year periods. Nutrient concentrations in leaves were averaged over 2-year periods. The yield data were regressed against foliar B concentrations, using SAS computer programs (SAS Institute, Inc., Cary, NC) [5]. Criteria for determining the regression model with the best fit were discussed earlier. A probability level of 0.05 or less was considered to be statistically significant.

Results and Discussion

Soil study. Hot water extractable B concentration in the unamended soil fines was 0.95 mg kg^{-1}. This concentration of extractable soil B was in the adequate range of 0.59 to 2.58 mg B kg^{-1} (on air-dried soil basis) found in California soils for healthy avocado orchards (Haas, 1943). However, it must be remembered that soil fines in this study comprised only 17% (dry weight basis) of the growth medium.

A linear increase of hot water extractable B concentration was observed in the soil fines as the rate of B application increased (Fig. 1). This linear regression model was used to calculate initial extractable B concentrations in soil fines due to B treatments (Table 1). In general, when soil extractable B concentration exceeds 5 mg B kg^{-1}, B toxicity symptoms in plants are likely to occur (Reisenauer et al., 1973). In this study, applied B levels equal to or greater than 11 mg kg^{-1} soil fines should have resulted in potentially toxic extractable soil B levels (Table 1).

Foliar B concentrations did not differ significantly among 'Sharwil' avocado trees prior to the start of the B treatments. The mean foliar B concentration was 69 ($\pm$ 4.8) mg B kg^{-1}. Nine weeks after the start of the B treatments, foliar B concentrations increased with increasing B application up to 89 mg B kg^{-1} fines and then decreased at the highest B application rate (Table 1). Similar results were found for total B leaf contents (data not shown). Foliar B concentrations of trees in the control treatment averaged 39 mg kg^{-1} (Table 1), which is a level below those recommended for optimal yields (Embleton and Jones, 1966; Coetzer et al., 1993; Whiley et al., 1996).

Dry weights of new leaves increased significantly with the first few increments of applied B and then decreased significantly with higher B application rates, particularly at B levels of or greater than 44 mg kg^{-1} soil fines (Table 1). Leaf area and tap root dry weight showed a similar response to increased B application rates (Tables 1, 2). The decrease in tap root growth of 'Sharwil' trees at higher B applications rates was similar to that found in two out of three sampling dates for total root dry weight of 'Hass' trees grown at B levels of or greater than 102 mg B pot^{-1} (Coetzer et al., 1994). This level of B shown to be toxic for young, 'Hass' trees on a per plant basis is similar to that found for young, 'Sharwil' trees, because 95 mg B pot^{-1} were applied to result in 44 mg B kg^{-1} fines.

There was no significant effect of B treatments on dry weights of fine roots (data not shown), and the weight of fine roots averaged 12.4 ($\pm$ 1.2) g. Length of fine roots tended to increase with the first few increments of added B, and then significantly decreased with increasing B application rates, particularly at levels equal to or greater than 44 mg B kg^{-1} fines (Table 2). Apparently, fine root lengths of 'Sharwil' avocados were affected by B treatments to a greater degree than fine root dry weights. Our results are in agreement with the field observation by Whiley et al. (1996) that avocado trees at an advanced stage of B deficiency had lost most of their feeder roots.

No visual B deficiency symptoms were observed during this study. Foliar B toxicity symptoms were observed two months after B application, and were characterized by leaf tip and marginal necrosis, interveinal chlorosis, and necrotic spots similar to those symptoms observed on 'Fuerte' avocado seedlings (Haas, 1929). In addition, "crinkling" of leaves, premature leaf abscission, depression of vegetative flushing, and stunted fine root growth (Table 2) were observed in young 'Sharwil' trees.

Boron toxicity symptoms were observed at foliar B concentrations greater than 190 mg kg^{-1} and soil B levels of or greater than 44 mg B kg^{-1} fines (Table 1). The foliar B concentrations associated with B toxicity in 'Sharwil' trees are within the range of 100 to 250 mg B kg^{-1} reported by Embleton and Jones (1966) to be in excess for avocado leaves. However, initial soil extractable B levels of or greater than 18 mg B kg^{-1} soil fines that were associated with B toxicity in 'Sharwil' avocados (Table 1) greatly exceeded the 5 mg B kg^{-1} soil reported by Reisenauer et al. (1973) to be toxic for a number of plant species. One possible explanation is that soil fines in this Tropofolist soil comprised only 17% of the total dry weight of the medium. As a result, a soil extractable B concentration of 18 mg B kg^{-1} soil fines could be considered to be "diluted" by inert rocks, resulting in an actual soil extractable B concentration of only 3 mg B kg^{-1} medium. Since percentage of soil fines in these Tropofolist soils vary greatly between farms in Kona, Hawaii, and even within a single orchard (C. Smith, personal communication), extractable B concentrations of soil fines alone do not appear to be adequate for predicting B requirements of 'Sharwil' avocados grown in these unique soils.

It is evident that this Tropofolist soil is low in B supply, because foliar B concentration in the absence of B fertilization was marginally low (Table 1). In addition, dry weights of new leaves and tap roots, leaf areas, and fine root lengths all increased with the first few increments of B fertilization (Tables 1, 2). It is also clear that high B application rates can severely depress dry weights of new leaves and tap roots, leaf areas, and fine root lengths (Tables 1, 2).

To estimate the adequate range of B concentrations in 'Sharwil' avocado leaves, growth of new leaves over a 13 week period were regressed against foliar B concentrations sampled 9 weeks after the start of B treatments, using non-linear models (Fig. 2). These non-linear models were selected based on statistical "goodness of fit," and not for physiological reasons.

The adequate B concentration for 90% of maximum dry weight of new leaves ranged from 37 ($\pm$4) to 65 ($\pm$5) mg B kg^{-1} (Fig. 2A), while that for 90% of maximum area of new leaves ranged from 31 ($\pm$13) to 78 ($\pm$10) mg B kg^{-1} (Fig. 2B). These B concentration ranges for 'Sharwil' avocado seedlings are lower than those previously reported for 'Fuerte' avocados of 50 to 100 mg B kg^{-1} (Embleton and Jones, 1966) or for South African avocados of 60 to 80 mg B kg^{-1} (Coetzer et al., 1993), but similar to that reported for Australian avocados of 40 to 60 mg B kg^{-1} (Whiley et al., 1996). These adequate B concentration ranges for 'Sharwil' avocados are based on vegetative growth, and it is well known that yield response curves can vary depending on whether the tissues sampled are vegetative or reproductive (Marschner, 1995). Later, we will compare these results with those obtained based on 'Sharwil' fruit yields.

Hydroponics Study. Within 30 days after initiation of B treatments, interveinal chlorosis and marginal necrosis were observed in leaves grown at 100 μM B. These symptoms are characteristic of B toxicity in avocados (Haas, 1929). At two months after initiation of treatments, there were no significant effects of B on leaf dry weight or leaf area. Average leaf dry weight per tree was 19.9 ($\pm$ 1.1) g and average leaf area was 26.9 ($\pm$1.5) m^2. Boron concentrations in leaves increased significantly with increasing B levels in solution, and the foliar B concentration associated with B toxicity symptoms was 232 ($\pm$23) mg B kg^{-1} (Table 3).

Avocado has been reported to be sensitive to irrigation waters having more than 92 μM B (Gupta et al., 1985). Also, Haas (1929) found toxicity symptoms in 'Fuerte' avocado seedlings grown in sand culture with 92 to 185 μM B. Thus, 'Sharwil' avocado trees exhibit B toxicity symptoms at solution B concentrations similar to those reported for other cultivars.

Eleven months after initiation of B treatments, leaves with deformed margins and a 'shot-hole' appearance were first observed at 0 μM B (Fig. 3). The symptom of 'shot-holes' in leaves is associated reportedly with B deficiency in field-grown avocado trees (Broadley et al., 1991; Whiley et al., 1996). However, this report is the first one to demonstrate that an induced B deficiency results in appearance of 'shot-holes' in 'Sharwil' avocado leaves.

At 14 months after initiation of treatments, increasing solution B levels significantly increased foliar B concentrations in new leaves, and significantly decreased percentage of deformed leaves (Table 3). The foliar B concentrations associated with

12 to 14% deformed leaves ranged from 10.3 to 13.5 mg B kg^{-1} (Table 3). The older leaves (produced prior to the start of the experiment) did not exhibit such leaf deformities. Haas (1943) reported that B deficiency caused terminal die-back, burned and distorted leaves, and corky, split midribs of leaves; however, he did not report appearance of 'shot-holes' in leaves. Foliar B concentrations in avocado seedlings associated with B deficiency symptoms ranged from 9 to 18 mg B kg^{-1} (Haas, 1943), levels which are similar to those found in this study to be associated with a 12 to 14% incidence of 'shot-holes' in 'Sharwil' leaves.

At the 14 month harvest, dry weights of new leaves significantly decreased with increasing B levels, particularly at 100 μM B (Table 3). There was no significant effect of B levels on new leaf area, and the new leaf area averaged 0.59 ($\pm$ 0.03) m^2.

On-Farm Field Trial. Soil-applied B significantly increased fruit yield in 'Sharwil' avocados grown in Kona, Hawaii (data not shown). Application of B did not affect occurrence of deformed fruit in this study (data not shown), perhaps due to multiple causes of fruit deformities. These results will be reported in a later paper.

Significant quadratic relationships between fresh weights of fruit summed over a two year period and averaged B concentrations in leaves were found only during the first two year period of the field trial (1990-92). Yields in the second two-year period (1992-94) were depressed and not affected significantly by foliar B concentrations, due to occurrence of severe droughts during the critical period of flowering and early fruit set. As a result, only data from the first two year period (1990-92) will be reported here.

Fresh weight of Grade 1 fruit summed over two years increased significantly (PR=0.05) up to a maximum yield of 68 kg $tree^{-1}$ at a foliar B concentration of 53 mg kg^{-1} (Fig. 4A) and then decreased at higher B levels. A similar response to B treatments was observed with respect to total fruit weight (Fig. 4B). Adequate foliar B concentrations associated with 90% of maximum yield for Grade 1 fruit and total fruit ranged from 40 to 67 mg kg^{-1} and from 42 to 70 mg kg^{-1}, respectively.

This range in optimal foliar B concentration is lower than that recommended by Embleton and Jones (1966) or Coetzer et al. (1993), but quite similar to that recommended by Whiley et al. (1996). These reported differences in optimal range of foliar B concentrations could be due to genotypic differences, or to differences in environmental conditions affecting the ratio of mobile to non-mobile B in avocados.

'Sharwil' avocados have been reported to be more sensitive to B deficiency than other cultivars (Piccone and Whiley, 1987). However, the range of foliar B concentrations required for optimal growth does not appear different from that of other cultivars in Australia (Whiley et al., 1996). Perhaps, 'Sharwil' avocados are inefficient in their uptake of B from soils, but not inefficient in their utilization of absorbed B.

Although statistically significant, the r^2 values indicate that only 12 to 13% of the variability in fruit yield was accounted for by foliar B concentrations. Such high variability due to uncontrolled factors is common in field trials. Possible factors other than foliar B concentrations that affected yield in this study were: a) temperature, solar radiation, and rainfall differences; b) soil fertility micro-site differences; c) root-stock differences, and d) variability in management practices between farms. Despite all these uncontrolled environmental and physiological factors in the field study, a similar range of adequate B concentration was found for 'Sharwil' avocados in both the on-farm study using fruit yields and the soil study in the greenhouse using vegetative growth.

Conclusions

Based on both vegetative growth in the greenhouse and fruit yield in commercial orchards, adequate foliar B concentrations of 'Sharwil' avocados ranged from approximately 40 to 70 mg kg^{-1}. Boron deficiency symptoms of 'Sharwil' avocados were characterized by appearance of 'shot-holes' and deformed margins in leaves. Foliar B concentrations associated with 12 to 14% deformed leaves ranged from 10.3 to 13.5 mg B kg^{-1}. Boron toxicity symptoms of 'Sharwil' avocados were found at levels of 100 μM B in nutrient solution. Foliar B concentrations of 'Sharwil' avocados associated with B toxicity symptoms ranged from 190 to 232 mg kg^{-1}.

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TABLE 1. Effects of increasing B application rates on estimated initial extractable soil B, foliar B concentrations at 9 weeks after start of treatments, dry weight of new leaves, and leaf area of 'Sharwil' avocados grown for 13 weeks in a soil study.

Added B, mg kg^{-1} soil fines	Initial extractable B [y], mg kg^{-1} soil fines	Foliar B, mg kg^{-1}	Dry weight of new leaves [z], g	Leaf area, m^2
0.0	2.2	39(14)	18.6 (3.1)	0.30 (0.05)
3.7	3.5	49(9)	28.0 (2.3)	0.43 (0.06)
11	6.0	82(19)	21.2 (5.4)	0.41 (0.09)
22	9.9	77(14)	26.1 (4.0)	0.45 (0.08)
44	18	254(65)	7.7 (2.0)	0.25 (0.08)
89	33	311(59)	8.6 (3.1)	0.19 (0.07)
178	64	189(44)	8.8 (3.3)	0.16 (0.07)
<u>ANOVA: PR > F</u>				
B		0.0006	0.002	0.003
Block		0.0200	0.870	0.300
B^2		0.0001	0.049	0.390

[y] Initial extractable B concentrations were estimated by the linear regression equation of Figure 1.

[z] Means are followed by standard errors of the mean in parentheses.

TABLE 2. Effects of several B application rates on dry weight of tap roots and root length of 'Sharwil' avocados grown for 13 weeks in a soil study.

Added B, mg kg^{-1} soil fines	Dry weight of tap root [z], g	Root length, m
0.0	25.8 (4.4)	27.0 (4.8)
3.7	30.8 (2.6)	28.6 (4.9)
11	29.1 (4.8)	27.0 (2.0)
22	31.6 (8.1)	31.1 (7.4)
44	18.4 (4.7)	20.1 (6.7)
89	17.8 (3.5)	20.4 (8.1)
178	20.9 (2.2)	15.0 (2.5)
<u>ANOVA: PR > F</u>		
B	0.04	0.03
Block	0.12	0.42
B^2	0.09	0.77

z Means are followed by standard errors of the mean in parentheses.

TABLE 3. Effects of solution B levels on foliar B concentration of new leaves at 2 and 14 months, dry weight of new leaves at 14 months, and incidence of deformed leaves of 'Sharwil' avocados at 14 months after treatment initiation.

B level,	Foliar B, mg kg^{-1}		Deformed	Leaf Dry
µM	2 months[z]	14 months	Leaves, %	Weight,g
0	27.7(1.2)	10.3(0.5)	12.0(2.8)	61.2(2.6)
1	34.5(4.2)	13.5(0.9)	14.1(4.9)	61.8(2.7)
10	66.8(7.7)	118.3(15.3)	8.6(3.7)	55.8(5.0)
100	231.8(23.3)	313.2(29.1)	1.6(0.5)	47.6(4.5)
Pr > F				
B	0.0001	0.0001	0.003	0.01
Block	0.6000	0.2900	0.013	0.36
B^2	0.2800	0.0007	0.310	0.35

z Means are followed by standard errors of the mean.

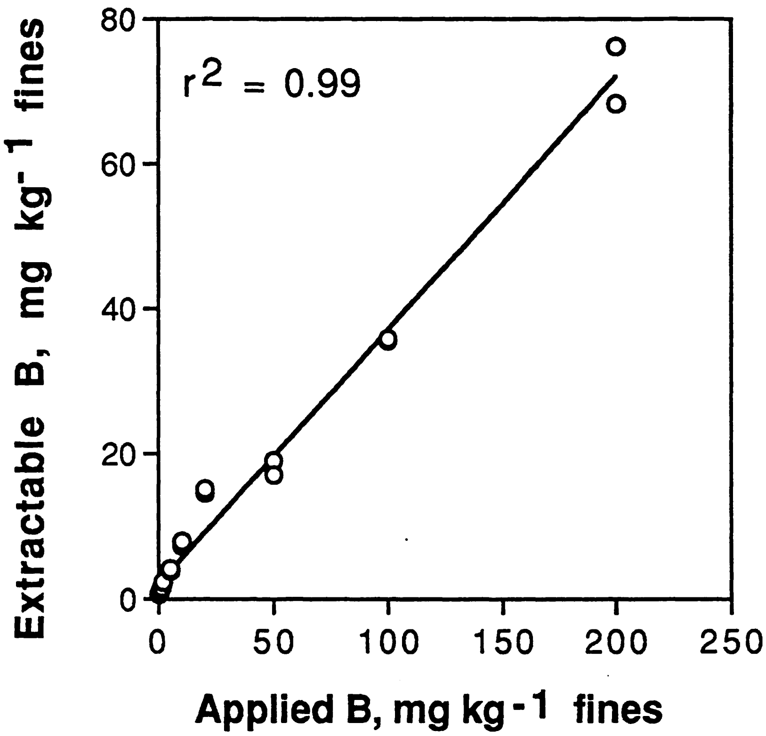
FIG. CAPTION

1. Effect of B application rates on extractable soil B in the soil study; linear regression equation: B(extractable) = 2.18 + 0.35*B(applied).

2. Relationship between increasing foliar B concentrations sampled at 9 weeks after start of B treatments and (A) dry weight or (B) area of new leaves of 'Sharwil' avocados grown for 13 weeks in the soil study. Nonlinear regression equations: (A) Dry weight = $B/(2.23 - 0.058*B + 0.000907*B^2)$; and (B) Area = $B/(55 - 0.024*B + 0.023*B^2)$.

3. Effect of decreasing solution B levels (B0 = 0 μM B; B1 = 1 μM B; B2 = 10 μM B; and B3 = 100 μM B) on incidence of "shotholes" and deformed margins in new leaves of 'Sharwil' avocados grown for 14 months of B treatments in the hydroponics study.

4. Relationship between averaged foliar B concentrations in mature summer flush 'Sharwil' leaves sampled in October 1990 and 1991, and (A) yield of Grade 1 fruit summed over a two year period (1990-92) or (B) total fruit yield summed over the same two year period in the on-farm study. Quadratic regression equations: (A) Yield (Grade 1) = $-40.0 + 4.05*B - 0.038*B^2$; (B) Yield (Total) = $-48.5 + 5.09*B - 0.0455*B^2$.



80
60
40
20
0
0
50
100
150
200
250
r2 = 0.99
Extractable B, mg kg-1 fines
Applied B, mg kg-1 fines

Fig. 1