

AN ABSTRACT OF THE THESIS OF

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Title: Relationship of Boron to Reproduction in Hazelnut (*Corylus*
avellana L.)

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Boron sprays produced fruit set increases in 'Barcelona' hazelnut orchards in 1984 and in 1985. The absolute fruit set was correlated with leaf B content but not with nut B. With relative fruit set (RFS), B content of nuts in May ($r = 0.63^{**}$) was more strongly related to set than B content in leaves sampled at any time or in nuts collected on later dates. Amounts of B in young nuts increased 2-fold with B sprays, but unlike leaf values, differences disappeared by mid summer. Because fruit set increases were obtained in both seasons with B sprays on trees whose leaf values are currently considered excessive, as well as those considered optimal or deficient, guidelines for B recommendations need revision. Since B levels of nuts in May was related to RFS in 1985, B content in May nuts from unsprayed trees might be universally low for optimum nut development. This would indicate that annual sprays of 600 ppm B may be required during the 2nd week of May.

Three nut disorders, brown stain (BS), nut shriveling and

seedlessness were described. BS appeared on the shell the last week of June and continued to occur until mid-August. Internal tissues became brown and watery and kernels aborted. The incidence of BS was 12% in 1982, 45% in 1983, 6% in 1984, and 0.1% in 1985. Shriveling of nuts was severe in 1984 (33%) but not in 1985 (8%). The percentage of blanks also varied with year, i.e. from 6% to 16% in 1984 and 14% in 1985. Following B sprays there was a slight reduction in these disorders. Although low B content in pith tissues was negatively correlated with BS low B may be an effect rather than a cause of BS.

Most B was partitioned in leaves early in the season whereas nuts and husks contained the highest amount of net B increase late in the season. Application of B in mid-May did not alter B partitioning in leaves, stems, nuts, and husks.

RELATIONSHIP OF BORON TO REPRODUCTION IN
HAZELNUT (Corylus avellana L.)

By

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Typed by G.K. Shrestha for Gyan Kumar Shrestha

This thesis is DEDICATED to my wife Ganga Shrestha
whose patience and constant inspirational support
made this work both possible and meaningful.

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RELATIONSHIP OF BORON TO REPRODUCTION IN
HAZELNUT (Corylus avellana L.).

Chapter 1

INTRODUCTION

The principle cultivar of hazelnut, or filbert, (Corylus avellana L.) in the United States is Barcelona. The Willamette Valley of Oregon produces more than 90% of the production in the U.S. Every year, whether 'on' or 'off' season, many flowers and nutlets drop early in the season (developmental dropouts) while mature nuts without kernels (blanks) drop later in the season before natural harvest drop. In certain years, other severe problems occur such as brown stain and nut shriveling. All of these problems contribute to a reduction in total harvestable nuts.

Boron is essential for normal reproductive growth and development in annual as well as perennial plants. Several tree fruit species, including apple (35), pear (22), and prune (49), that received B applications produced a higher fruit set than those without B supplements. In hazelnuts, Baron (15,17) observed a positive response to foliar B sprays. Italian prune trees, considered B-sufficient by the standard August leaf analysis, produced a higher set following post-harvest B application than following either the spring application or the unsprayed controls (49). In hazelnuts, Baron (15,17) reported that spring B applications (30 May) benefited hazelnut set greater than winter applications (2 February); however, his study was confined to one

orchard and one B concentration. Kelley (136) applied B at 500 ppm concentration at 3 different timings in one orchard located near Corvallis. However, fruit set was not improved after the sprays. Because of these conflicting reports, a 2-year study was conducted to clarify the effect of foliar B sprays on fruit set in hazelnut orchards located at different locations in the Willamette Valley. This present study was undertaken to investigate the relationship of B to hazelnut reproduction with the following objectives:

1. To determine the optimum timing and optimum concentration of B.
2. To determine the response of foliar B application in 'Barcelona' orchards which had 20 ppm B to 117 ppm B in the previous August leaves.
3. To determine if there was a relationship between fruit set (cluster set) with previous August leaf B levels.
4. To investigate whether B content in current season vegetative or reproductive tissues was related to fruit set.
5. To record yearly variation in the incidence of brown stain and to see if mineral contents in leaf or nut tissues were associated with this disorder.
6. To record nut shriveling and blanks and to see if B sprays could alleviate these disorders.
7. To understand B partitioning in B-treated and untreated nuts, leaves, stems, and husks of fruiting twigs.

Chapter 2

REVIEW OF LITERATURE

Introduction

Boron was reported as a constituent of plants for the first time by Wittstein and Apoiger (257), who, in 1857, obtained boric acid in ash of seeds of an Abyssinian plant. They postulated that the element could have a role in a plant's life cycle. The stimulatory effect of B on the growth of lupins (70) and peas (178) was demonstrated and the usefulness of B for crop plants was recognized at the beginning of the 20th century. Because B supplements also increased growth and yield of several vegetables, the element was considered essential for plant growth in 1910 by Agulhon (2). Other researchers found a profound growth stimulation of cereals (166,208) and vegetables (221,245) following B addition to the media. Besides annual plants, woody perennials also were found to require B for proper growth and development. For example, as early as 1930, Haas (107) observed multiple bud formation on citrus trees grown in a medium lacking B. Since then, evidence has been presented that B is necessary for many fruit tree species including apple (10,42,116,168,169), pear (113,259), quince (119), and stone fruits (114,211).

POSTULATED ROLES OF BORON IN THE PLANT

Boron may be associated, directly or indirectly, with plant metabolism, because in the absence of B, physiological processes

in plants are often irregular and result in abnormal growth and development. The literature on postulated roles is voluminous, yet the primary function of B in plants is still unknown. Some of the metabolic roles proposed for B are briefly described.

Cell Division and Cell Enlargement

Boron plays roles in two basic processes of plants, cell division and cell enlargement. Under B-lacking conditions, the growth of roots, stems, or fruits is reduced. The reduction in growth could be related to a decrease in cell division or cell elongation. For example, cessation of growth of intact squash root tips was associated with inhibition of cell division (68), but in other species the limiting factor was cell elongation. In Vicia faba, as B was removed from the nutrient solution, there was a linear inhibition of root-tip cell elongation (142,143).

The cessation of cell division and cell elongation resulted in restriction of cell wall formation and failure of cells to become organized for mitosis in spring field beans, Trifolium pratense L. and Vicia faba (254,255). Sometimes meristematic cells divide continuously without differentiation (45). It was hypothesized that B was necessary for converting uridine diphosphate D-glucose to pectin, an important compound for cellular functions. Arora and Singh (8) applied B to guava trees and increased the pectin content in plant tissues, especially fruits, a direct evidence in support of the above hypothesis.

Nucleic Acid Metabolism

The level of nucleic acids (DNA and RNA) in plants could be influenced by B in the medium in which they are grown because the element was reported to be important in nucleic acid metabolism (196). Rajaratnam and Lowry (201) observed that the primordial region of B-deficient oil palm seedlings contained a lower amount of both DNA and RNA than B-treated plants. Between these 2 acids, B has a greater effect on the RNA content because B supplement increases RNA levels more than DNA levels. For example, Whittington (255) recorded a 20% increase in RNA, but not in DNA, content in B-treated cells. He suggested that cell division in B-deficient tissues ceases at a low level of RNA, and that it is not due to a lower content of DNA. He found that the DNA content was low in B-supplied bean cells compared with B-deficient cells. A significant increase in RNA content of B-sprayed cotton plants was also found by Saini et al. (209) at a lower concentration of boric acid, 0.125%, but not at a higher level, 0.250% B, which suppressed RNA biosynthesis.

Protein and Amino Acid Composition

Following B supplements, protein and amino acid content of crop plants may increase. In 1939, a microchemical study on the effects of B deficiency in cotton seedlings led Wadleigh and Shive (241) to suggest that B be considered a necessary element for the normal course of protein synthesis. This could have been a consequence of B effect on nucleic acid metabolism. Many years later, an increase in protein content was demonstrated in wheat grains by applying B (65,74). Mechanisms for B-stimulated

increase in protein content are unknown. It was suggested that the higher protein content in leaves and a lower amount in grains in B-deficient plants could be due to a low rate of translocation of proteins from the leaf to grains. Bussler (46) found an increase in the storage of assimilates, including proteins and fats, in B-deficient sunflower leaves. This accumulation was caused by inhibition in translocation of these substances out from the leaves. He reported that the inhibition was because there were fewer well-differentiated conducting tissues.

In barley (14), groundnut (218), lucerne (228), and tomato (54,118), B affected amino acid composition. Boron has a positive effect on increasing amino acids which are essential in human diets, but not most non-essential amino acids. Iqtidar and Rehman (126) observed a linear relationship between increasing supply of B and essential amino acid content in wheat grains, whereas the relationship was negative with all non-essential amino acids except histidine and tyrosine.

Activity of Enzymes

Boron influences the activity of certain enzymes involved in physiological processes in plants. In corn and faba bean, the absorption of phosphate in B-deficient roots was reduced because of decreased ATPase activity. Addition of B restored the enzyme activity and membrane functions (198). The activity of catalase, acid phosphatase, starch phosphorylase, or invertase was low in pollen grains of B-deficient corn plants but not in B-sufficient

plants (1). Boron also complexes with 6-phosphogluconic acid. This complex inhibits the action of 6-phosphogluconate dehydrogenase (151).

However, not all enzymes reduce their activity in B-deficient tissues. For example, ribonuclease and amylase activities were higher in pollen grains obtained from B deficient corn plants (1). The activity of IAA oxidase was increased in B-deficient squash-root sections (31). However, this enzyme had lower activity in sunflower and corn plants that were subjected to several days of B deficiency (219). This indicates that, when B is withheld, the same enzyme may possess variable activity either in the same species or in different species.

It is possible to increase enzyme activity from a lower to a higher level with B application. For example, B treatments increased the activity of ribonuclease in young shoots and germinating seeds of wheat (75) and of polyphenoloxidase (PPO) in immature 'Italian' prune fruits (48). With B addition, the activity of PPO was increased in B-deficient sunflower, tomato, peas, and corn plants, but not in wheat or sorghum (220). The stimulation of enzymic reactions from foliar sprays of B was also noted in guava fruit (8).

Carbohydrate Translocation

Photosynthates, such as carbohydrates, translocate from leaves to other parts of a plant. This process is associated with the amount of B present in the plant. Gauch and Dugger (97,98) reported that there was a reduction in sucrose translocation in B-

deficient plants. This reduction was associated, perhaps, with an imbalance between sugar and starch contents in leaves (81). Scott (215) suggested that B deficiency causes excessive polymerization of sugars at sites of sugar synthesis and, as a result, sugar is translocated less. Ju et al. (133) found a lower sugar content and higher levels of other compounds such as goitrin and thiocyanate ion in B-deficient turnip roots.

Other evidence shows that B may not be involved directly in the movement of sugars. For example, the translocation of photosynthetically-incorporated ^{14}C in bean plants was increased by adding NAA to the meristems of B-deficient plants. The translocation was interrupted only when phloem movement was disrupted (82); hence, B may not be a primary requirement for sugar translocation in bean plants. Excessive callose formation has been reported in B-deficient tissues (207). This callose plugs sieve plates which reduces translocation of photosynthates (235). In Phaseolus vulgaris and Cucurbita maxima toxic levels of B also produced excess callose (88,171).

Production of Phenols

Higher production and accumulation of phenolic compounds may occur in B-deficient plant organs. Watanabe et al. (247,248) observed a higher level of phenols in tissues deficient in B. They identified phenolic compounds such as scopolin, esculin, isoquercitrin, and scopoletin in tobacco and sunflower. In tomato, lettuce, radish, and sunflower plants, caffeic and chloro-

genic acids were accumulated (193). There was an increase in polyphenol and a decrease in monophenol content in tomato root tips deficient in B (159). Coumarin also accumulated in olive trees (121).

Boron may also be associated with flavonoid synthesis in plant tissues, especially in leaves of the oil palm (202). Because the flavone to flavonone ratio was higher in B-deficient and lower in B excess conditions in tomato, Carpena Artes et al. (53) emphasized that flavonoid biosynthesis was a B-regulated mechanism in higher plants. Rajaratnam and Lowry (201) found a higher content of ferulic and vanillic compounds in leaves of oil palm seedlings when B was omitted from the growth medium. The cause of such an excess production of phenolics under B deficiency was related to a lack of borate complexes. This is explained thus, when the level of these complexes in plant tissues goes down, the activity of 6-phosphogluconate dehydrogenase ceases and as a result there is a higher production of phenols (151).

Plant Growth Regulators

There is some relationship between movement of growth regulators and B content in plants. For proper growth of plants growth regulating chemicals are translocated from a source to the sink. Boron facilitates such translocation processes. Gauch and Dugger (97) reported that B accelerated the movement of photosynthates, especially sucrose, from leaves to other parts of bean and tomato plants. Since there was a close association between the translocation of growth-modifying substances and movement of

photosynthates (153,175,206,249), addition of B in the presence of sugars was believed to accelerate auxin movement from bean leaves to stems. Mitchell et al. (176) applied various synthetic growth modifiers (2,4-D NH₄, IAA, 2,4,5-T, and NAA) on leaves of bean plants grown in a solution with or without B. They measured translocation of these compounds from leaves to stem based on stem curvature and found that increases in curvature were 115% to 1,520% over that observed on plants not receiving boron.

Boron also is believed to help maintain a hormonal balance in plants (82,83,154). At deficient B levels, there was a higher concentration of IAA in primordial regions of oil palm (201) and in root segments of bean (69). As compared to B-sufficient tissues, when B is deficient, the activity of IAA oxidase is low because of higher accumulation of phenolic compounds; thus, the level of IAA in tissues increases. Since higher levels of this auxin is toxic, growth is inhibited and tissues become brown (214). Auxins, such as NAA, in the presence of B may help regulate DNA replication and RNA synthesis in pea plants (125). The level of the growth inhibitor, ABA, also increased in B-deficient berries immediately after set (214). These findings support the concept that an optimal B concentration is needed to keep a balance between growth promoters and growth inhibitors in plants. This concept that an optimal level of B is required is supported by agricultural research.

AGRICULTURAL IMPLICATIONS OF BORON LEVELS IN PLANT TISSUES

Standardized optimum levels of B for normal growth have been established. For example, the Oregon State University Fertilizer Guide recommends that, for optimum productivity, prunes should have 35 to 80 ppm B in mid-shoot leaves in August whereas below 25 ppm is deficient and over 100 ppm toxic. Plum trees were also reported to require 25 to 60 ppm for desirable growth, and below 20 ppm was deficient (152). Hernandez and Childers (117) found toxic symptoms in peach at 100 ppm B or more. Baron and Stebbins (18) stated that filbert (hazelnut) leaves need 30 to 80 ppm B for optimum productivity and that spring B sprays should not be applied when leaves contain 100 ppm or more in the previous August. For sweet cherry (58) and apples (59), 30 to 80 ppm B were optimum. A level of B below 30 ppm in August leaves is deficient, and above 80 ppm B is excessive for sweet cherry (58). Boron concentration lower than 20 ppm in August leaves was considered deficient and above 100 ppm was toxic for apple growth (59). In British Columbia, peach leaves always showed toxicity symptoms when the B content in May leaves exceeded 130 mg/kg, but symptoms appeared only occasionally at levels of 50 to 85 mg/kg. Neilsen et al. (180) suggested that 20 to 50 mg/kg in July leaves would be a desirable range for normal growth of peach trees.

Boron Deficiency Symptoms

Plants grown under B deficiency express one or more of the following symptoms.

Vegetative phase. Roots became dark brown with weak growth and

die-back started from the tips (3,103,107,108,109,130,205). Such roots became rough, elongated, with abnormally thick periderm (3,103) followed by decay of rootlets (107).

Leaves became yellow, chlorotic, necrotic, rosetted, and curled with corky or split veins or rachis, and new twigs dried (107,108,109,113,121,127,191,205,211). Bark splitting and early defoliation (135) have been noted on B-deficient plants. Fruit trees also had multiple bud formation (107,110). The number of leaflets was reduced in some species (111). Lack of B also induced brittleness of leaves (95,109,135,191) and stems (3,130).

Reproductive phase. Boron deficiency causes reproductive irregularities, such as delayed flowering (95,103,254), production of tassels with nonfunctional pollen (1,238), aborted embryos or poorly developed seeds (24,173,244), and blasting of blossoms (20,204,259). In peaches, Kamali and Childers (135) noted fewer flower buds, a longer blooming period, lower pollen viability, and poor fruit set (5,114,121,191,265). Sometimes a white exudate, which later became brown, was seen on the youngest flower bud and petiole ends (191) or on fruits (244). Kamali and Childers (135) noted fruit cracking as well.

Anatomical changes. Boron deficiency symptoms on vegetative or reproductive organs perhaps result from changes in the anatomy and histology of plants. Reed (205) and Warington (246) observed disorganization and brown discoloration of phloem and cambium cells which became necrotic and disintegrated later

(110,132,134,242). Xylem development may also be poor (246). The upper epidermal as well as palisade cells may collapse (40). In some cases, the palisade and spongy mesophyll layers compacted together, thus reducing intercellular spaces (138). Cell wall formation, cell differentiation, and mitotic cell division were reduced in B deficient tissues (142,242). Most collenchyma cell walls became thinner, while the phloem parenchyma and the ground parenchyma walls were thicker (223).

Boron Toxicity Symptoms

As shown above plants cannot tolerate B deficiency and hence express this as morphological and anatomical irregularities. Similarly, when levels of this element exceed an optimum concentration toxic symptoms appear. Early signs of B toxicity in Cucurbita pepo were lower leaf conductance (to water vapor), reduced CO₂ fixation, and decreased chlorophyll content (158). Other symptoms follow such as leaf distortion, chlorosis, necrosis, leaf defoliation, and shoot die-back were also reported (43,67,89,135,149,235,250,256). Roots became brown (240) and some plants died (67,161). With excess B, more callose was deposited in the parenchyma tissue of Phaseolus vulgaris leaves (171) and in sieve tubes in petioles of Cucurbita maxima (88). In addition, Webber (250) found degradation of chloroplasts and protoplasts.

The toxic level of B in reproductive tissues of various plant species results in the production of fewer flower buds, reduced pollen viability, lower fruit set (135), exudation of gum (250), poor and slow germination of seeds (103), and failure to differe-

ntiate female flower buds (188).

Boron-Related Physiological Disorders in Plants

Higher plants often show disease-like symptoms in vegetative and/or reproductive parts which, because they are not primarily caused by insects, fungi, bacteria, or any other microorganisms, are considered to be physiological in origin. Many such symptoms are caused by, or at least are closely associated with, mineral deficiencies. Some disorders associated with lack of B in 20 or more plant species are listed below.

<u>Plant species</u>	<u>Disorders</u>	<u>References</u>
<u>Fruit Crops</u>		
Apple	Internal cork	(10,42)
	Drought spot	(168)
	Flesh browning	(116)
	Die-back	(169)
Citrus	Multiple bud	(107)
Grape	Lead disease	(220)
	Bud failure	(9)
Papaya	Fruit deformation	(244)
Peach	Fruit cracking	(94,135)
Pear	Blossom blast	(259)
	Twig blight	(113)
	Die-back	(78)
Prunes	Brushy branch	(114)
Quince	Bitter pit-like	(119)

Raspberry	Crumbly berry	(165)
	Die-back	(11)
Stone fruits	Little leaf	(211)
Strawberry	Fruit deformation	(181)
Walnut	Snake-head	(212)
	Leaf and twig deformation	(47)

Vegetable Crops

Cabbage	Internal breakdown	(132)
Cauliflower	Internal browning	(77)
Celery	Stem cracking	(200)
Garden beet	Black spot	(132)
Rutabaga	Brown heart	(160)
Sugar beet	Heart rot	(36,37)
Swedes	Raan (Brown heart)	(182)
Turnips	Brown heart	(160)

Other Crops

Oil palm	Bud rot and little leaf	(93,144)
Tobacco	Top sickness	(146)
Tulip	Decoloring and broken tops	(124)
Zinnia	Flower bud blasting	(204)
Alfalfa	Yellows	(39)

Boron Content in Leaves and Flowers

Plants require an optimal amount of B for proper growth of leaves and flowers. Levels below critical amounts may produce irregular symptoms in the vegetative and/or reproductive tissues.

For example, Gupta and Cutcliffe (104) observed brown heart disorder of rutabaga at leaf B less than 20 ppm. The growth of Japanese pear tree was reduced and abnormal leaf symptoms were seen at B levels below 15 ppm (265). At incipient B deficiencies, pear trees suffered from drying, shrivelling, and dying of flower clusters, which was described as 'blossom blast' (21,259). Similarly, bud blasting has been attributed to B deficiency in Zinnia (204).

Applications of B either in the soil or on the foliage raised leaf boron levels in apples (19,72,112,116), pears (20,121), filberts (145,190), cereals and legumes (56), and corn (229,230). Boron sprays applied in the fall did not raise the B content significantly in leaves collected the following August from prune orchards (60). However, such application increased B levels in dormant buds and spur tissues (48,49). Boron content in leaves and other tissues may be influenced by application time, weather conditions, crop species, etc. For example, climatic factors may play a role in yearly variation in B content in some parts but not in another tissue of the same plant. Leaves of misted and non-misted trees collected 80 days after full bloom contained similar B levels (72) which demonstrated that B is not leached out of leaves by rain, whereas flowers at full bloom on non-misted trees contained more B than the misted ones. Fall-applied B sprays also increased the B content in flower buds and flowers (48,49). The evidence indicated that the B content of a flower may be influenced by environmental factors, especially by rain or

humidity. Hanson and Breen (115) created artificial rains to quantify the amount of B that could leach from flower buds. They observed that such simulated rain did not leach B from these buds readily; however, flowers blooming on excised branches in high relative humidity (86%) contained 13% less B per flower than those kept in low humidity (29%). They also noted that following fall B sprays there were increases in B levels of 'Italian' prune flowers during a cool spring but not in a warm spring.

The optimum B concentration for reproductive growth may be higher than that for vegetative growth. Several studies have indicated that the highest concentration of B is in the reproductive organs. For example, B accumulated in flowers more than in other plant parts of apple (29), corn (30), lily (25), tobacco (26), Oenothera (100), cherry, apple and pear (260,261). In Oenothera, stigmas contained the highest amount. In some species, such as rye, male reproductive tissues, especially anthers and pollen grains, contained higher B as compared to female reproductive parts (155). Among different parts of an apple fruit the highest B was in the endocarp and the lowest in the floral tube (43).

Seasonal Variation in Boron Levels

Boron content of flowers and leaves varies through the growing season. The level in buds changes very little during dormancy and increases rapidly as bud growth begins in the spring. The highest B content was at full bloom (44,99,261). Woodbridge et

al. (261) reported that pear, apple, and cherry fruit buds did not store sufficient B for their development, but drew on B from the soil or from nearby reserves as soon as initiation of growth was started. Similar translocation and movement of B from nearby wood reserves to developing flowers was noted in 'Italian' prune trees (115).

Some fluctuation in leaf B content over time has been noted and it varies with the plant species. For example, as the growing season progressed, leaf B content increased in rutabaga (104) and pecan (262) while in apple (43), red raspberry (128), and filbert (145) there was a higher leaf B early in the season (June - July) as compared to later (September). Spiers (222) observed in 'Tifblue' rabbiteye blueberry high leaf B during April and early May, low during harvest and high again in October. The age of leaves (position on the cane) also has a significant influence on this variation. This is particularly true in red raspberry primocane leaves. Hughes et al. (122) divided red raspberry canes into 7 positions, each with 2 leaves, starting from the tip (position 1) to 15 cm down (position 7). They reported a higher B content in younger leaves (position 1 to 3) than older leaves (position 4 to 7). The younger leaves showed considerable fluctuation and older leaves had relatively less fluctuation through the season .

Rootstock Influence on Boron Levels of Scion Leaves

Rootstocks can substantially affect mineral composition of scion leaves (12,62,64,90,156,251,258). In pears, graft compati-

lity and interstem genetics had no apparent influence on uptake and translocation of nutrients to the scion; the main controlling factor was the root system (61,62). Roots play important roles for controlling B transport in plants (41,85). Fallahi et al. (91) also observed changes in apple fruit minerals which were attributable to rootstocks.

In 1935, Eaton and Blair (85) reported 50% more B in leaves of sunflower plants grafted on artichoke roots than when self-rooted. Leaves of artichoke on sunflower rootstock contained 50% less B. They also observed a 3-fold increase in B concentration of leaves of Chinese box orange grafted on to lemon. The concentration of B in leaves of the scion was less if grafted on cultivars which normally accumulate less B; whereas, the level increased if grafted on cultivars which accumulated higher B (85). Fallahi and Larson (89) observed that rootstock influenced B content in pear. They found a higher amount of B in leaves of Bartlett cultivar grafted on seedlings of Pyrus calleryana, than on seedlings of P. betulaefolia, Old Home, or Old Home x Farmingdale stocks. When d'Anjou cultivar was grafted on Bartlett seedlings, the scion leaves had higher B than when grafted on P. betulaefolia and Old Home stocks. However, differences were not significant when grafted on P. calleryana seedlings. Leaves of Starkspur Golden Delicious apple grafted on OAR 1 rootstock contained higher B than when this cultivar was grafted on other rootstocks (90). Leaves of prune trees grafted on plum rootstock showed slightly less B compared to those grafted on peach (64). In

a reciprocal grafting of two tomato cultivars, T 3238 (less efficient) and Rutgers (more efficient in B uptake), Brown and Jones (41) demonstrated that roots control transport and hence influence B content of scion leaves.

Gene Control of Boron Requirements of Plants

Plant species and cultivars require varying amounts of B for proper growth and development. Among 11 mineral elements in leaves of 13 apple species, Westwood and Bjornstad (252) observed the greatest variation, 255%, for boron. Among 14 red raspberry genotypes, the B content in leaves ranged from 14 ppm in Malling Jewel to 35 ppm in BC 201 (128). Similarly, Brown and Ambler (40) found several-fold more B required in the soil for T 3238 tomato than for Rutgers. Some cultivars, like Rutgers, are particularly efficient in extracting B from the soil and transporting it from the root to the above ground parts.

In some plant species there is good evidence for genetic control of uptake and transport of boron. A single recessive gene is responsible for controlling B transport in celery (199) and in tomato (4,243). In apples, a low level of Ca and B induces bitter-pit. The resistance to this disorder correlates with a high level of these elements in leaf and fruit tissues. Korban and Swaider (141) identified two major genes controlling these mineral levels and hence, the resistance. Blamey et al. (28) indicated that B levels in sunflower hybrids were inherited from the parents used in a hybridization program.

Boron Mobility in the Plant

Boron is considered to be relatively immobile in the phloem. Roots take up B from the soil, and it then moves passively in the transpiration stream and accumulates in older leaves (140). That redistribution of B from older leaves to growing tissues via the phloem system is limited (84,87,98,123,172) is indicated by the observations that when B is withheld from the medium, young actively growing leaves show symptoms of B deficiency. This mechanism of low mobility of B over long distances, as suggested by Oertli and Richardson (183), is the unidirectional flow of the transpiration stream which causes a cyclic movement of boron within the leaf. Because B is less mobile in the phloem, boron that translocated from leaves or other tissues to flowers and fruits may not be enough to meet the B requirement for reproductive growth. This is why localized application of B has helped to correct blossom blast of pears and increased fruit set in fruit trees containing optimum B levels for vegetative growth. Neales (179) observed relatively little movement of B from cotyledons to radicles in germinating bean seeds when they were transferred from plus-boron to boron-free solutions. Neales inferred, from this, that B must be present in the solution for normal growth of radicles.

Several reports indicate that B may have limited mobility in the phloem system. Scott and Schrader (216) noted that there was upward movement of B from lower mature leaves of grapes to actively growing terminal parts when B was withheld in the root

environment. Campbell et al. (51) found that fruit and seed production of peanut and clover were the same for plants grown in media low in B and for those supplied with added boron. Because of this, these authors suggested that B was translocated in the phloem in these species. In prunes, flowers on cut branches which were forced to bloom indoors accumulated as much B as those on intact trees. Hanson and Breen (115) concluded that these flowers were supplied with B from nearby reserves in the branches. In radish, although the major part of foliar-applied B remained in the treated leaves, some B had been translocated to nontreated aerial parts and to roots (57). Similarly, B mobility has been suggested for turnip (92), broccoli (23), cotton (167), stone fruits (86), and apple (236). Cerda et al. (55) studied B mobility in 'Verna' lemon trees. Based on the rate of B accumulation in the fruit and the ratio of B concentration in the fruit and leaves, they concluded that B had intermediate mobility in plants.

POLLEN AND FRUIT SET

Pollen Germination

Boron is essential, or at least beneficial, for in vitro germination of pollen grains of many species (50, 73, 121, 131, 138, 147, 150, 203, 225, 232). Pollen of some species responds to added B in the germination media while that of others does not. The ability of a plant to supply B to pollen differs with the species and hence pollen varies in the amount of

endogenous B, which may be a determining factor for germination. For example, pear pollen had a higher endogenous B level (100 ppm B) than pine pollen (20 ppm B or less). Because the percentage of germination was lower in Pyrus (60 to 66%) than in Pinus, pear pollen often responded to supplemental B in in vitro germination (225). Boron levels in pollen are influenced by the amount of B available to the plant during development (239). Pollen from B-deficient corn plants contained less boron (5.8 to 7.5 ppm B) and had higher germination in in vitro conditions when B was added, whereas pollen from B-sufficient plants contained more boron (10.8 ppm B) and did not respond to supplemental B (1). Pear pollen collected from trees that received continuous B application for 4 years had a higher percentage of germination than pollen from untreated trees (7). Responses of alsike clover (177) and Forsythia (239) pollen to supplemental B also depended on the level of endogenous B.

Plants grown in B-deficient media may produce non-viable pollen (138,238). Corn plants produced non-functional tassels that lack sporogenous tissues or floral appendages (1) and silks became non-receptive (238). Even when pollen from high-B plants was supplied, fertilization of such silks failed. There was poor set or barren cobs.

Stimulation of pollen germination by B is not universal, however. Boron had no effect on pollen germination of Capsicum annuum (237), Crotalaria juncia, and Corchorus capsularis (239). Increased germination of B-treated plum pollen was recorded by

Thompson and Batjer (232), but not by Blaha and Schmidt (27). Kim et al. (139) applied B to the germination medium and found no effect on the germination of filbert pollen.

Foliar applications of B have improved pollen germination of sugarbeets (138), grapes (184), and strawberries (106). Boron application also improved anther dehiscence in strawberry.

Pollen Tube Growth

Pollen tube elongation may be accelerated by supplemental B (6,50,174,203,232,239). Macleod (170) reported that the elongation process was different from the germination process. Whereas several inhibitors of growth and metabolism (maleic hydrazide, trans-cinnamic acid, indoleacetate, and abscisic acid, indole-3yl-acetic acid at high concentration, and ethylene) inhibited germination to varying extent, they promoted tube elongation. The B-induced increase in tube length was not related to sugar absorption nor to respiration (185). Boron may have roles in complexing with compounds that inhibit the elongation process. For example, a diphenol such as caffeic acid inhibits pollen tube growth of several plant species (164). Because B has been demonstrated to form complexes with diphenols (266), the presence of this element in the medium could prevent the formation of certain phenolic compounds that inhibit pollen tube growth in in vitro conditions. Pollen tube growth, however, was not influenced by levels of endogenous B in pollen (49,254). In Zea mays, both Ca and B addition was necessary for maximum pollen tube growth

(194,195).

In a review and interpretation of physiological roles of B in plants Gauch and Dugger (98) said that when B was absent from the pollen-germination medium, pollen tubes were short and cork-screw-like with a high proportion of bursted tubes. The bursting of pollen tubes was assumed to be the result of "unregulated water intake".

Fruit Set

The fruit setting process is complex and multidimensional, and is influenced by many factors. Among mineral supplements, B applications have been used for many tree fruit species to increase fruit set; e.g. apple (35), guava (8), pear (22), citrus (66,186), and prune (60,115). However, responses to B applications varied with species and cultivars. Following B sprays 'Stayman' apples increased fruit set, where as 'Jonathan' and 'Golden Delicious' cultivars did not (35). In New Zealand, B-sprayed Delicious apple trees increased set (76). On the other hand, B treatments reduced fruit set in 'Discovery' and 'Cox's Orange Pippin' apples (263). This suggests that apple trees may respond to B, but consistent results are unlikely. The response of prune and cherry to B sprays depended on the concentrations of B in August leaves; when the B level in the leaves was above 60 ppm, sprays could induce toxicity and reduce fruit set (253).

Schuster and Stephenson (213) found an increase in set of hazelnuts and walnuts by B application. When Painter and Hammer (190) applied B at 14 g (0.03 lbs)/tree, hazelnut set increased

some years, but not in others; hence the effect was inconsistent. Baron (15,16,17) reported that foliar applications of B resulted in a higher percent set as compared to non-treated hazelnut trees. He found the highest fruit set over control from the 30th May application. Kelley (136) applied 500 ppm B on foliage at 3 different times during spring, including 29 May, and found no significant effect on the set of hazelnut. In all these hazelnut experiments, the cultivar used was 'Barcelona'.

Variable responses to sprays are likely to be associated with many factors. For example, Hanson and Breen (115) studied the fruit set response to B of 'Italian' prunes for two years. They concluded that B affected fruit set during a cool spring, when set was low (3.2%), but not in a warm spring when set was high (12.25%). Callan et al. (49) and Chaplin et al. (60) indicated that the time of spray was important; B sprayed prebloom was not effective as compared to the fall postharvest spray. Other studies indicated that the stage of flower development was an important factor. To increase fruit set 'Le Conte' pears (13) needed 200 ppm of boron at the white ballon stage and again shortly before harvest. Similarly, Davison (76) recorded a 12% increase in fruit set of apple trees that received B at open cluster and at petal fall.

Boron is necessary for normal reproductive development of plants. In the absence of B, not only flower bud differentiation (254) and flower development (120) was affected, but also a total failure in fruit set was noted (121). An incipient B deficiency (a

temporary lack of B supply to leaves, blossoms, and twigs prior to and during bloom which was associated with unfavorable weather conditions for early root growth) caused blossom blast in pear orchards (21,259). Boron supplements either in fall or in spring, however, alleviated this problem and thereby increased fruit set (20,129). In papaya, B application increases the number and weight of fruits by increasing the proportion of female and hermaphrodite flowers (192).

Seedless nuts in pistachios (33,71,102) and hazelnuts (148,189,233) result from embryo abortion. In almond, ovule abortion is associated with callose deposition in the chalazal scar of the ovule which blocks the flow of metabolites to the ovules (197). When B was deficient in sugarbeet and bean plants, there was greater accumulation of callose deposits in sieve plates which limited the translocation of photosynthates (207,235). This suggests that B may help maintain the flow of metabolites within the plant system, because B applications have reduced malformed seeds as well as seedlessness in hazelnuts (187) and in some wheat varieties (96).

Chapter 3

FOLIAR-APPLIED BORON INCREASES FRUIT SET IN 'BARCELONA'
HAZELNUT

Abstract

Boron sprays produced fruit set increases from 3 to 72% in 1984 and from 3 to 33% in 1985 in 'Barcelona' hazelnut orchards. The absolute fruit set was correlated with leaf B content with r values ranging from $+0.36^*$ to $+0.54^{**}$, but not with nut B. With relative fruit set (RFS), B content of nuts in May ($r = 0.63^{**}$) was more strongly related to set than B content in leaves sampled at any time or in nuts collected on later dates. Amounts of B in young nuts increased 2-fold with B sprays, but unlike leaf values, differences disappeared by mid summer. Because fruit set increases were obtained in both seasons with B sprays on trees whose leaf values are currently considered excessive, as well as those considered optimal or deficient, guidelines for B recommendations need revision. Since B levels of nuts in May was related to RFS in 1985, B content in May nuts from unsprayed trees might be universally low for optimum nut development. This would indicate that annual B sprays may be required. Foliar sprays of 600 ppm B in April damaged young leaves and shoot tips; thus delaying sprays until the 2nd week of May is recommended.

Introduction

Foliar boron (B) applications have been reported to increase fruit set in some species of fruits (4,5,6,9). 'Italian' prune trees that were not considered B-deficient according to leaf analysis standards exhibited a higher fruit set when B sprays were applied (7,8). In a 2 year study of 'Italian' prune trees, also not considered B-deficient, Hanson and Breen (12) reported inconsistent fruit set response from fall-applied sprays. Boron increased set during a cool wet spring when crops were low but not in a warm one when crops were heavy. Baron (2,3) reported that B sprays enhanced fruit set in one hazelnut (filbert) orchard, whereas Kelley (13) found no response in another.

The timing of B application may be important. In prunes, prebloom B sprays were ineffective as compared to positive responses with postharvest sprays (7,8). The stage of flower development at which B was applied was critical for inducing a higher set in 'LeConte' pears (1) and in apples (10). In hazelnuts, Baron (2,3) sprayed B from Feb. to May and increases in set over controls were highest with the 30 May application.

The purpose of this study was to determine if varying B nutritional status of orchards might explain the conflicting reports on hazelnut response to B sprays (3,13). We wanted to determine the optimum spray timing and concentration, to see if there was a relationship between fruit set and previous August leaf B levels, and to investigate whether B content in current

season vegetative or reproductive tissues is related to fruit set. This paper presents the results of a 2-year study of foliar B applications in several hazelnut orchards.

Materials and Methods

Boron sprays were applied in 'Barcelona' hazelnut (Corylus avellana L.) orchards in the Willamette Valley of Oregon for 2 growing seasons. In 1983-84, 4 orchards were selected that had 25 to 93 ppm B in 1983 Aug. leaves. Based on Oregon State University (OSU) standards, leaf B content of orchard # 1 was below normal (25 to 30 ppm B), orchards # 2 and # 3 were normal (30-80 ppm B), and orchard # 4 was excessive (more than 80 ppm B). Treatments included 2 levels of B (300 and 600 ppm), 6 dates of applications (20 Oct. 1983, 20 April, 13 May, 11 June, 27 June, and 12 July, 1984), and one unsprayed control. In each orchard, there were 6 replications in a randomized block design. Boron was applied as Solubor (78% $\text{Na}_2\text{B}_8\text{O}_{13} \cdot 4\text{H}_2\text{O}$ and 20% $\text{Na}_2\text{B}_4\text{O}_7 \cdot 5\text{H}_2\text{O}$) (US Borax Company) with 300 ppm X-77, a non-ionic wetting agent (Shell Oil Company). Sprays were applied to the point of drip with a handgun sprayer (9 gal/min, PSI of 200 lbs). Trees were observed for 10 days after each application to detect spray injury.

For fruit set counts, trees of similar size and vigor were selected in each orchard. Using 3 to 5 branches, a total of 500 to 600 flower clusters were counted on each of the 78 trees in each orchard. Nut clusters were hand-picked from trees during the 3rd and 4th week of Aug.

In 1984, leaves and nuts for mineral analysis were sampled separately in orchard # 1 from unsprayed trees and from those that received 600 ppm B sprays applied in Oct. 1983, in April or

in early June 1984. Twenty leaves from the mid-shoot area of current season growth were sampled on all sides of a tree at monthly intervals from April to Sept. Nuts were sampled at 2-week intervals from 9 June (50 to 70 nuts) through 9 August (25 to 30 nuts). In the other 3 orchards, leaves and nuts were sampled only once, on 9 Aug. For all tissue samplings, leaves and nuts from 2 of the 6 replicated trees were composited for each of 3 replications per treatment.

In 1985, the number of replications was increased because of the large amount of within-plot variability in fruit set in 1984. The number of trees (10-16) was determined by using the 1984 error term. The average fruit set for these 4 orchards was highest when 600 ppm B was applied on 13 May. Hence in 1985, only one treatment consisting of 600 ppm B applied on 15 May and one unsprayed control were used. Five orchards were selected to represent a range in B status as indicated by the previous Aug. leaf levels. As per OSU standards, one was B-deficient (20 ppm B), 2 were in the normal range (35 and 50 ppm B), 1 had above normal (86 ppm B), and 1 had excessive B (117 ppm B). Methods of B application and fruit set counts were the same as in 1984.

In 1985, both leaves and nuts were sampled periodically in all 5 orchards. Leaves were sampled at 20-day intervals from 25 May to 17 Aug. Twenty one leaves (7 leaves per tree) were sampled for each of untreated controls and B-treated trees per orchard at every collection date. In 1984, the greatest difference in B levels between nuts of treated and control trees was observed at

the earliest sampling date. Therefore, in 1985, nuts were sampled beginning at an earlier date, 25 May, and every 10 days until 27 July. Because of their smaller sizes at earlier dates 70 to 100 nuts per sample were necessary for the tissue analyses while at later dates only 15-40 nuts were used. As in 1984, 3 replications per treatment were analyzed.

Leaves and nuts (husks removed) were washed in a solution of 10 g EDTA (Ethylenedinitrilo tetraacetic acid, disodium salt) and 10 g Alconox in 20 liters of distilled water. Tissues were rinsed 2 times with tap water and once with distilled water. Fresh weight was recorded before washing and dry weight after tissues were dried at 70°C for 48 hours. The dried tissues were then ground in a Willey Mill (20 mesh screen). Nitrogen was determined by an automated micro-Kjeldahl apparatus (14). Plant tissues were analysed for P, K, Mg, Ca, S, Mn, Fe, Cu, B, and Zn by ICP emission spectroscopy (11) after dry ashing at 500°C and being dissolved in 5 ml of 20% HNO₃, which was diluted to 5% before analysis.

Both linear correlations and stepwise multiple regression between fruit set and leaf or nut mineral contents were computed for each sampling date. Since absolute fruit set in control trees varied between orchards, a measure of the relative difference between untreated and B-treated trees was useful. Therefore, the relationship between relative fruit set (RFS) and leaf or nut B levels was also determined. RFS is defined as the fruit set of a given sample divided by the average fruit set of B-treated trees

for a particular orchard. This expression eliminates the variability between orchards in fruit set.

Results and Discussion

Effects of B sprays on fruit set

Foliar B applications increased fruit set over controls in both seasons (Table 3.1). In 1984, every orchard responded positively to both B concentrations. Including all timings and both concentrations, increases in fruit set over controls ranged from 18 to 72% in orchard # 1, from 7 to 27% in orchard # 2, from 3 to 29% in orchard # 3, and from 8 to 45% in orchard # 4. Although, the overall mean for B-treated trees significantly differs from controls, increases in individual orchards were significant for only orchard # 1 and for one timing, 13 May. The lack of significance in other treatments and other orchards may be partly because of large tree-to-tree variation and too few replications.

In 1984, fruit set increases occurred over a wide range of B spray timings. Considering all 4 orchards the increase over control was minimum (18%) with the 12 July application and maximum (29%) with the 13 May spray (Figure 3.1). Fall-applied B sprays averaged 22% higher set than controls. The effectiveness of fall B sprays on hazelnuts has not been reported, although such sprays benefited prune set (7,8,12). Since application dates, except in orchard # 1, and the interaction between dates x B concentrations were not significantly different in individual orchards, fruit set data from all 4 orchards was pooled. With this pooled data B treatments significantly increased the overall set 29% over

controls (Table 3.1). Baron (2,3) also obtained increased set when B was applied to trees at 15-day intervals from 1 Feb. to 30 May. He found maximum set from 30 May B sprays. This 2-week difference in optimal spray timing, as compared to our results, could be due to seasonal differences. Also, the orchard used by Baron was located in a cooler area where there may be 1 to 2 weeks delay in phenological development.

In 1985, the greater number of replications resulted in the detection of significant fruit set increases in 4 of the 5 orchards (Table 3.1). Fruit set increases in B-sprayed trees were 15% in orchard # 1, 25% in orchard # 2, 33% in orchard # 3, 14% in orchard # 4, and 3% in orchard # 5. The orchard (# 1 in 1984 = # 3 in 1985) which had the lowest set in controls both years had the best response.

Although overall increases in set following B sprays were significant both years, there was 29% increase in 1984, the low crop year, and only 15% increase in 1985, the high crop year. Following B treatments, Baron (2) found 30% or more increased set over control in 1968, when set was low as compared to 19% increase in the previous year when fruit set was higher. Stebbins (15) reported that Solubor sprays enhanced hazelnut yield (pounds of nuts/tree) in 3 of 4 years. There was no response in 1975 when the crop was unusually heavy, and the maximum increase, 23%, was in 1974, when yield was lowest (15). Similar results have been reported on other fruit crops. Hanson and Breen (12) recorded significant fruit set responses of 'Italian' prune trees to B

foliar sprays in a low crop year, but not in a high crop year. Boron sprays significantly increased initial set of Cox's Orange Pippin apples in 1973 when set of controls was 57/100 fruit buds but the effect was not significant in 1974 when control set was 105/100 fruit buds (16). Although, B increased the final (harvest) set 23% in 1973 and 4% in 1974, in neither year was the increase significant for Cox's Orange Pippin apples.

Seasonal changes in boron content in leaves and nuts

Leaf tissues. Seasonal patterns for B levels (ppm, dry weight basis) in leaves of control and sprayed trees from the orchard sampled in 1984 were similar to the mean of 5 orchards in 1985; hence, seasonal changes in leaf B content were shown only for 1985 (Figure 3.2A). Leaf levels (ppm) increased slightly over time in control trees. When we applied B the 2nd week of May, leaf B levels tripled early in the season (25 May), remained high throughout the season, and then decreased somewhat as the growing season ended. In both control and B-sprayed leaves total B content, $\mu\text{g}/\text{leaf}$, increased until 27 July, after which date levels decreased. Fall-applied treatments slightly increased B content (58 ppm in B-treated vs. 50 ppm in controls) in leaves sampled the following Aug., but differences were not significant. Callan et al. (7) also found no significant difference in B levels in Aug. leaves of treated and untreated 'Italian' prune trees with B sprayed the previous fall. Apparently, B was diluted through vegetative growth in spring and summer.

Nut tissues. There was a similar seasonal trend in B content of nuts in both years, thus levels are given only for 1985 (Figure 3.2B). Unlike leaf values, nut levels (ppm) decreased through the season. Although sprays increased B content (ppm) 2-fold in nuts early in the season, by the 2nd week of July B levels were virtually the same in both sprayed and control nuts. This decrease in concentration was due to the rapid increase in nut size and a high rate of accumulation of dry matter.

Mid-May foliar sprays doubled total B content in 25 May nut tissues, from 0.24 μg to 0.46 μg per nut (Figure 3.2B). The relative difference in B content between unsprayed and B-sprayed tissues was merely 3% by 27 July when unsprayed nuts contained 12.82 μg while treated nuts had 13.20 μg . The absolute difference in B content between treated and untreated nuts in July averaged 0.24 μg , almost the same as in nuts collected on 25 May (0.22 μg). Thus, B content in the nuts was increased only by the amount absorbed by the nuts when the spray was applied. Although leaf B levels are also increased by sprays B apparently does not move from leaves to nuts. This is further supported by the fact that, in 1985, B concentrations in May nuts from control trees were remarkably similar in all orchards (19-27 ppm B) despite large differences in leaf B content the previous Aug. (20-117 ppm B). In both years, by the 4th week of July, nuts from both treated and control trees in all orchards had similar B levels (7 to 10 ppm) regardless of B treatment or broad differences in current season Aug. leaf levels (30 to 114 ppm in 1984 and 26 to 143 ppm in

1985).

Relationship between fruit set and B levels in leaves and nuts

Boron levels in leaves: previous year. Although a slight trend is apparent in the 1984 data, the relationship between boron levels of leaves collected the previous Aug. and fruit set (Table 3.1) was not consistent in the 2 years. For example, fruit set (50.5%) in orchard # 5 with 117 ppm B, an excessive level by August standards, was comparable to that (51%) in orchard # 1 which was deficient (20 ppm B), and higher than in orchards # 2 (43.6%) and # 3 (37.5%) which are considered to be in the normal range, i.e. 35 ppm and 50 ppm B. Although orchard # 5 had the highest leaf levels, it did not have the highest set.

Also, there was no consistent relationship between Aug. leaf levels and the degree of fruit set response to B sprays. In 1984, Orchard # 4 with excessive leaf content had higher (24%) fruit set increases over control than orchard # 2 (12%) with the optimal B level. On the other hand, in 1985, the response was greater in orchards # 2 (25%) and # 3 (33%) where Aug. leaf values were optimal than in orchard # 1 (14%) which was deficient. Because 4 of the 5 orchards in 1985 responded to applied B, regardless of previous Aug. leaf levels, it is not possible to predict the need for sprays on this basis. Callan (6) was also unable to relate previous Aug. leaf levels to fruit set responses in prunes following B sprays. Since in our study B sprays which caused an increase in fruit set also raised Aug. leaf levels to a level currently considered excessive, clearly these guidelines for B

fertilization are inappropriate for hazelnuts.

Boron levels in leaves: current season. Boron content of current season leaves was positively correlated with fruit set at all collection dates. Correlation coefficients (r values) were 0.51** (25 May), 0.40* (15 June), 0.36* (6 July), 0.47* (27 July), and 0.54** (17 Aug.). However, r^2 values were low (0.13 to 0.29) and explain only a small portion of the variability in fruit set. Since B treatments increased both leaf B content and fruit set, one would expect the higher B leaves to be associated with the B-treated plots having higher fruit sets. Relationships are much weaker if either control or B-treated plots are evaluated separately. These low correlations support the concept that B levels in leaves may not be the main factor contributing to fruit set. The r^2 values between RFS and B content were 0.32 for May leaves (Figure 3.3) and 0.19 for August leaves (Figure 3.4). Other factors, such as cultural practices, tree vigor and age, tree spacing, and annual pruning are also involved.

Levels of B in current season nuts. By early June B levels in nuts were similar in all orchards although fruit set varied greatly; thus, nut B content, also, was not related to fruit set. When correlation coefficients between RFS and nut B levels for all sampling dates were computed, only May nut B was related significantly, $r = 0.63$ ** (Table 3.2). This r value, although higher than r values for leaf analyses at any date, was still not high enough to be predictive of the need for B sprays since it could explain only 40% of the total fruit set variability (Figure

3.5). Even if the relationships were stronger, utilizing May nut analyses to evaluate the need for spring applied B, is not logistically feasible.

Correlation between fruit set and concentrations of other minerals in leaves and nuts

Correlation coefficients were calculated for fruit set and 10 other essential mineral elements in leaves or nuts. Nitrogen, P, K, S, Mg, Mn, Fe, and Cu were correlated with fruit set (Table 3.2A & B). Several elements were as strongly, or more, related to fruit set than was B, but, with the exception of Mn, relationships were generally inconsistent. At all sampling dates, leaf minerals significantly correlated (positively) with fruit set, in order of r values, were $Mn > K > S > B$ (Table 3.2A). Phosphorus and Mg were negatively correlated, but the latter element was significant only on 6 July. In stepwise multiple regressions between fruit set and 11 leaf minerals on each sampling date Mn and B were consistently the first 2 elements related to fruit set with r^2 values ranging from 0.66 to 0.72. Adding other minerals only slightly increased r^2 values (Appendix IV).

Nut minerals that significantly related to fruit set throughout the season were Mn (positive) and Cu (negative) (Table 3.2B). Phosphorus (negative) was significant only in June. The stepwise multiple regression for nut minerals indicated that the relationship of these elements to the set were inconsistent (Appendix IV). Cu (earlier dates) and Mn (later dates) appeared

on the first step while K, Fe, B, Zn, S, and P were on the second step. Since Mn content of leaves and nuts was the most highly correlated with fruit set (Table 3.2A & B). Mn fertilization should be investigated further to see if soil or foliar application will increase hazelnut set.

Spray injury

All B sprays applied on 20 April damaged the tender, small, young leaves and some shoot tips. Symptoms were more severe with 600 ppm concentration. Leaf margins became pale green within 2 days, followed by chlorosis and then necrosis within 7 days. Some leaves eventually became completely necrotic and fell. Leaves not severely injured, however, continued to grow but were cup shaped, mostly downwardly, and deformed. Although these early symptoms initially appeared severe, on the average, fruit set was still higher than controls.

We conclude from this study that most hazelnut orchards in the Willamette Valley of Oregon require B sprays for optimal fruit set. The existing recommended Aug. leaf levels (30 to 80 ppm B) for optimal tree performance are totally inappropriate for predicting optimum productivity. Apparently, high levels of B in young developing nuts is essential for maximum fruit set, and these high levels are best achieved by sprays applied directly to the developing nuts. From these studies it is evident that hazelnut trees have a much higher B tolerance than other orchard trees. Boron toxicity has been observed on mature trees at leaf B content of 384 ppm (Harry B. Lagerstedt, personal communication).

Further studies are necessary to determine more precisely what levels are toxic and if those toxic levels occur after prolonged annual applications at realistic rates.

Table 3.1. Fruit set response and August leaf boron content of 'Barcelona' hazelnut as influenced by 600 ppm B sprays applied in spring.

Orchards	Fruit set (%)		August leaf B (ppm)	
	control	+ boron	control	+ boron
-----	-----	-----	-----	-----
1984: 1 ^z	22.5	38.7*	51 (25) ^y	79**
2	33.0	37.0	86 (53)	114*
3	30.0	36.3	40 (77)	78**
4	36.5	45.2	30 (93)	89**
average	30.5	39.3**	52 (62)	75**
1985: 1	51.0	58.4**	59 (20)	129**
2	43.6	54.6**	26 (35)	73**
3 ^z	37.5	50.0**	32 (50)	89**
4	63.1	71.8*	79 (86)	143**
5	50.5	52.0	68 (117)	113**
average	49.1	56.5**	53 (62)	109**

^yFigures in parentheses were B contents in the leaf for the previous year.

^zThe same orchard but treatments were applied to different trees.

* & ** are significance levels at 0.05 and 0.01, respectively.

Table 3.2A. Correlation coefficients for fruit set and elements from leaf tissues sampled at various dates in 1985.

Date	N	P	K	S	Ca	Mg	Mn	Fe	Cu	B	B ^Z
Leaf:											
5/25	.49**	-.48**	.67**	.52**	.26	-.31	.74**	.71**	-.48**	.52**	.57**
6/15	.32	-.43*	.56**	.58**	.26	-.21	.76**	.21	-.42*	.40*	.43*
7/06	.44*	-.53**	.54**	.36*	-.14	-.37*	.71**	-.09	.16	.38*	.45*
7/27	.44*	-.50**	.61**	.39*	.20	-.32	.72**	-.04	.39*	.47**	.45*
8/17	.56**	-.60**	.67**	.70**	.18	-.40	.70**	-.11	.34	.54**	.44*

* & ** are significance levels at 0.05 and 0.01, respectively.

^Z_r values between relative fruit set and B content in leaves.

Table 3.2B. Correlation coefficients for fruit set and elements from nut tissues sampled at various dates in 1985.

Date	N	P	K	S	Ca	Mg	Mn	Fe	Cu	B	B ^Z
Nut:											
5/25	.21	-.07	.35*	.34	-.05	-.26	.37*	.39*	-.66**	.27	.63**
6/05	.11	-.44*	-.07	.19	.28	-.32	.64**	.08	-.68**	.08	.13
6/15	-.24	-.45*	.14	.08	-.18	-.41*	.58**	.18	-.69**	-.03	.30
6/26	.17	-.48**	.06	-.31	-.35	-.46**	.61**	-.01	-.77**	-.16	.11
7/06	.04	-.18	.35	.32	-.15	-.14	.55**	.09	-.65**	-.18	.07
7/17	.32	.01	.43*	.45*	-.01	.02	.64**	-.01	-.47**	-.03	.09
7/27	.02	-.08	.29	.20	.06	-.08	.60**	.33	-.61**	.01	.07

* & ** are significance levels at 0.05 and 0.01, respectively.

^Zr values between relative fruit set and B content in nuts.

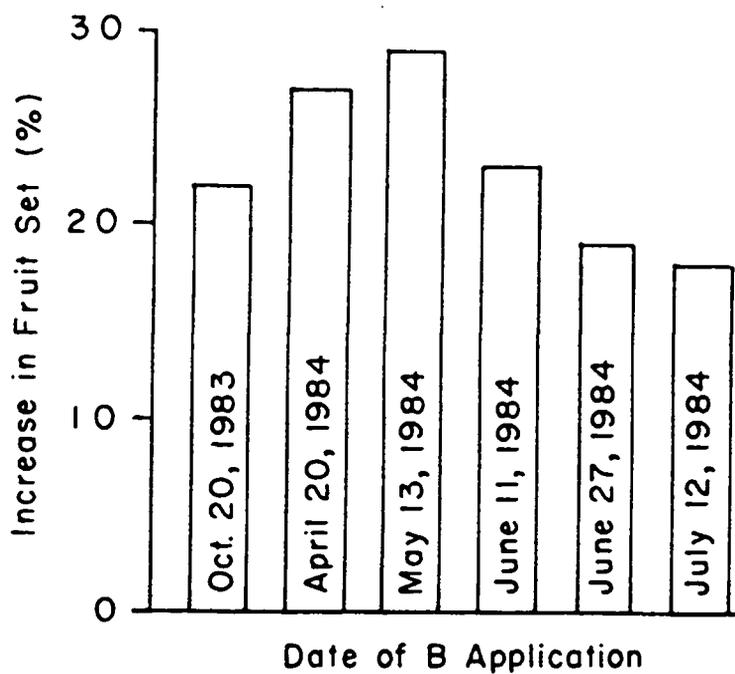


Figure 3.1. Increase in fruit set over control in response to time of B spray at 600 ppm concentration in 4 orchards during 1984.

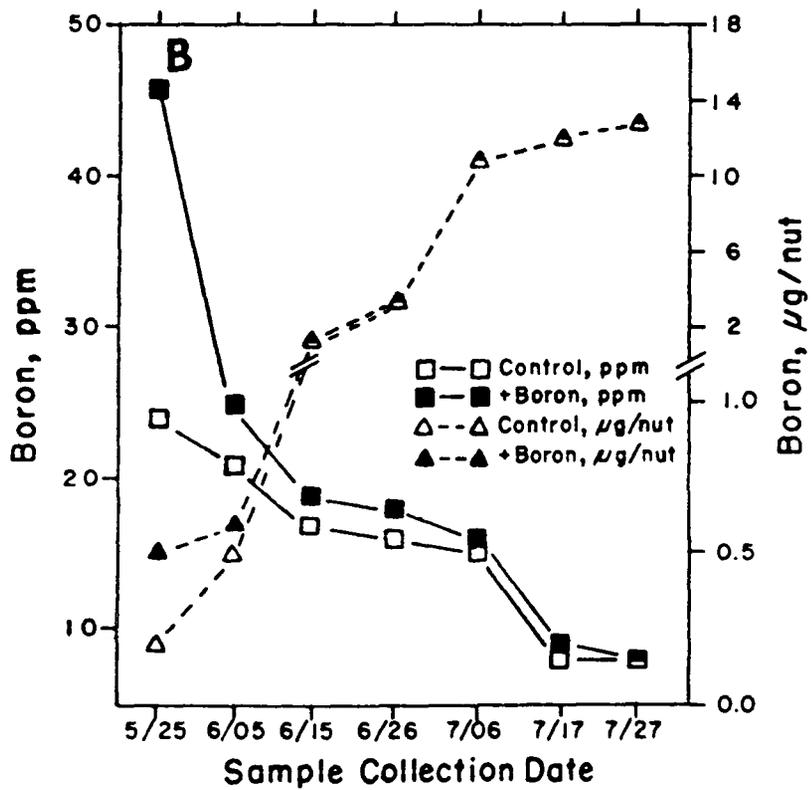
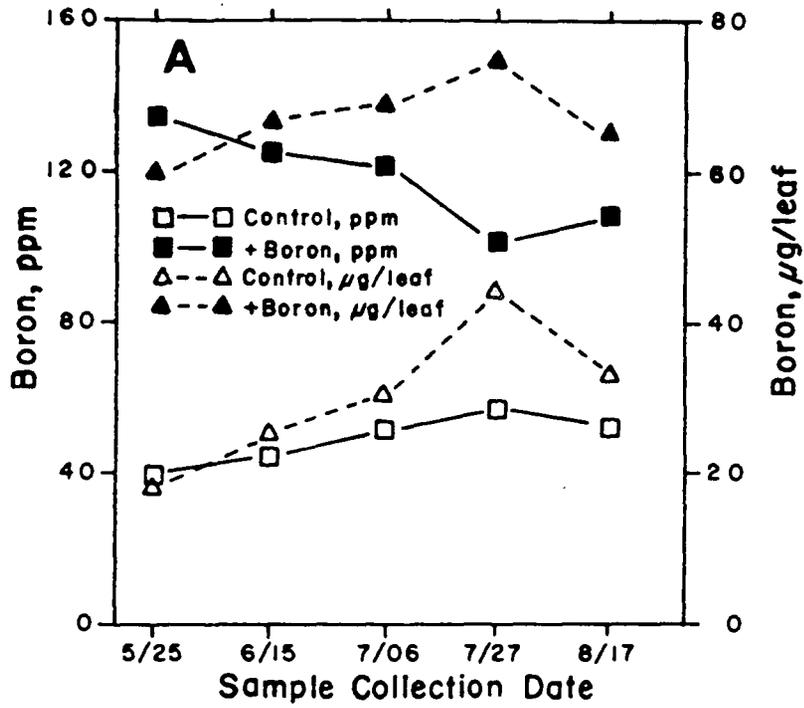


Figure 3.2. Seasonal changes in B content of leaves and nuts from boron-treated and from control trees in 1985. A. Leaf B vs. dates of sampling. B. Nut B vs. dates of sampling.

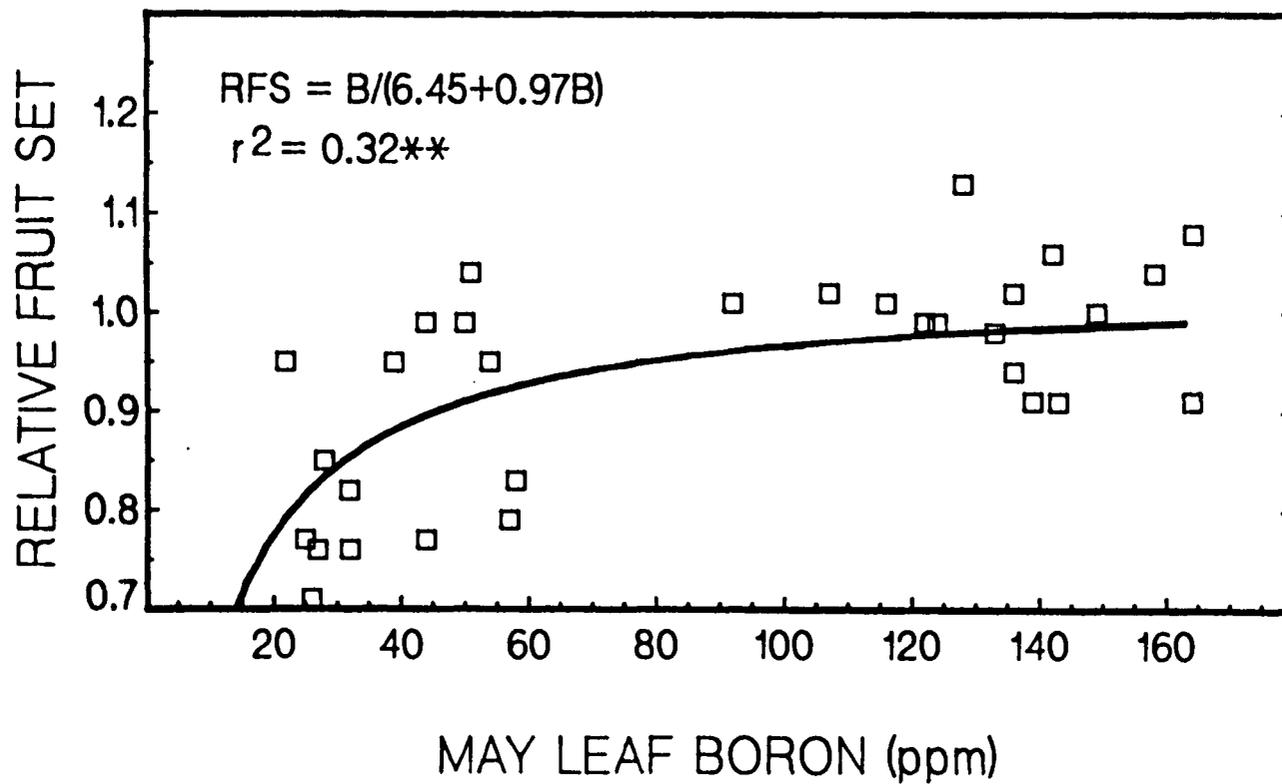


Figure 3.3. Relationship between relative fruit set and B content in May leaves of 'Barcelona' hazelnut.

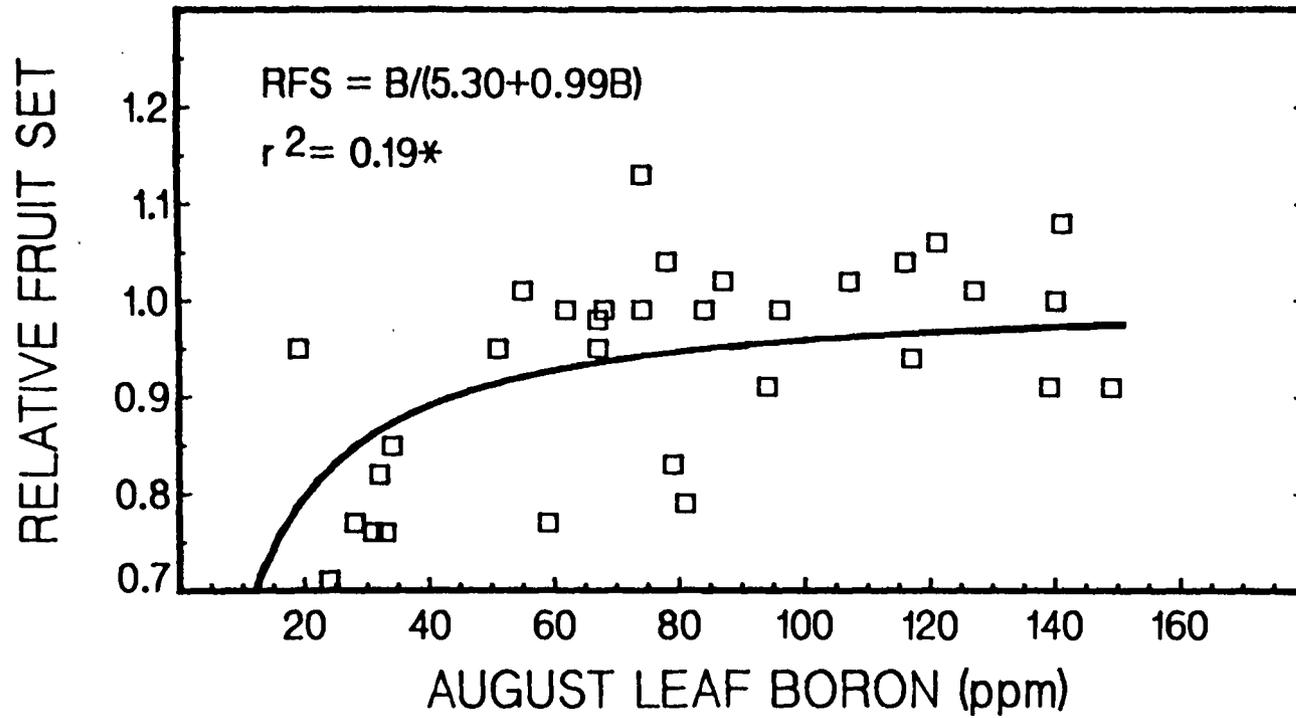


Figure 3.4. Relationship between relative fruit set and B content in August leaves of 'Barcelona' hazelnut.

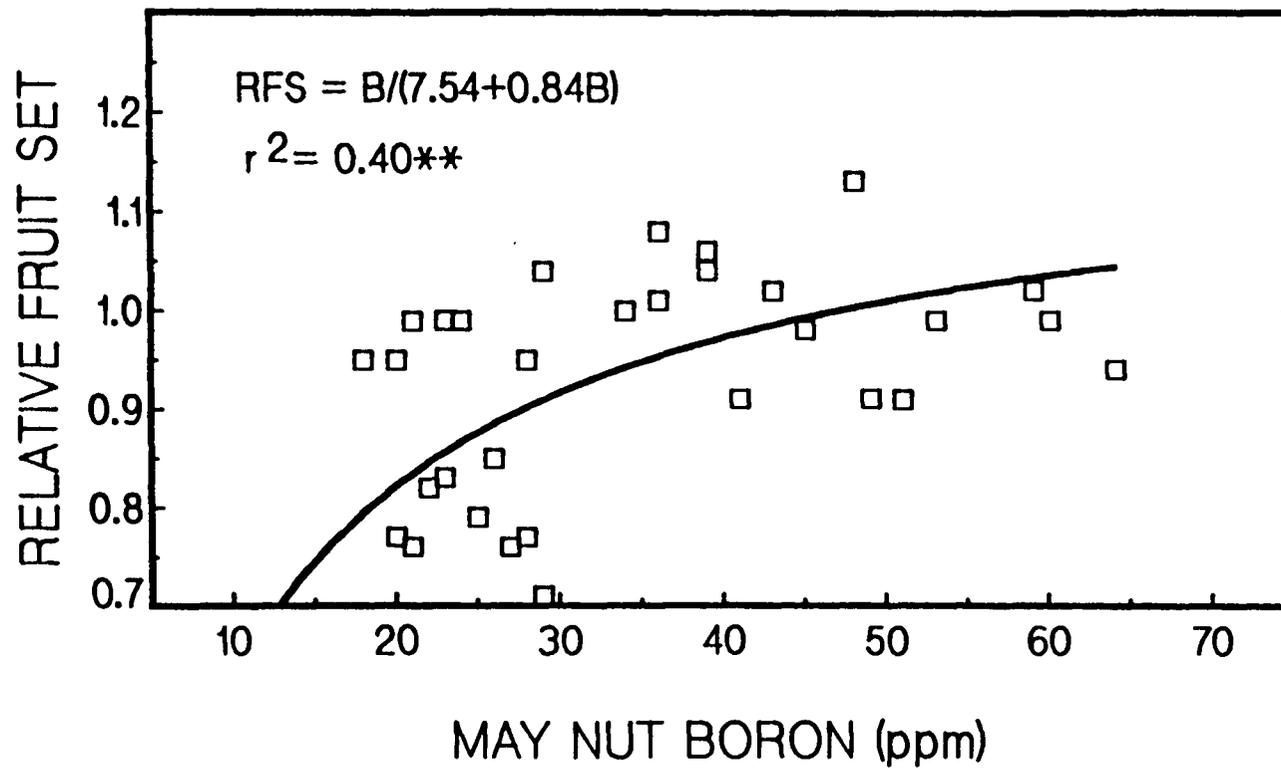


Figure 3.5. Relationship between relative fruit set and B content in early nuts of 'Barcelona' hazelnut collected on 25 May, 1985.



Plate 3.1. Fruiting twigs of 'Barcelona' hazelnut.

- A. Normal twig with normal leaves in unsprayed controls.
- B. B-spray injured twig with marginal scorching, deformed, and cup-shaped (downwardly) leaves following 600 ppm B application on April 20, 1984.

Literature Cited

1. Badawi, A.M., A.M. Sweidan, M.A. Fayek, and A.H.I. El-Hawary. 1981. Effect of B, Zn, and Ca on growth, fruit quality and storage ability of 'Le Conte' pear. Research Bulletin, Faculty of Agriculture, Ain Shams University, No. 1656, p.20.
2. Baron, L.C. 1968. Waking up the sleeping giant. Proc. Nut Growers Soc. Ore. and Wash. 54: 22-28.
3. Baron, L.C. 1973. The value of boron sprays on filberts. Proc. Nut Growers Soc. Ore. and Wash. 58: 43-44.
4. Batjer, L.P. and A.H. Thompson. 1949. Effect of boric acid sprays applied during bloom upon the set of pear fruits. Proc. Amer. Soc. Hort. Sci. 53: 141-142.
5. Bramlage, W.J. and A.H. Thompson. 1962. The effects of early-sprays of boron on fruit set, color, finish, and storage life of apples. Proc. Amer. Soc. Hort. Sci. 80: 64-72.
6. Callan, N.W. 1977. Effect of boron sprays on fruit set, fruit quality, boron distribution and floral morphology of 'Italian' prune (Prunus domestica L.). Ph.D. Thesis, Department of Horticulture, OSU, Corvallis, Oregon.
7. Callan, N.W., M.M. Thompson, M.H. Chaplin, R.L. Stebbins, and M.N. Westwood. 1978. Fruit set of 'Italian' prune following fall foliar and spring boron sprays. J. Amer. Soc. Hort. Sci. 103: 253-257.
8. Chaplin, M.H., R.L. Stebbins, and M.N. Westwood. 1977. Effect of fall-applied boron sprays on fruit set and yield of 'Italian'prune. HortSci. 12: 500-501.

9. Chauturiya, I.A. 1974. Effect of trace elements on the percentage of setting of citrus fruits. Subtrop. Kul't. (2): 48-50.
10. Davison, R.M. 1971. Effect of early-season sprays of trace elements on fruit setting of apples. N.Z. J. Agr. Res. 14: 931-935.
11. Issac, R.A. and W.C. Johnson. 1985. Elemental analysis of plant tissue by plasma emission spectroscopy: Collaborative study. J. Assoc. Off. Anal. Chem. 68: 499-505.
12. Hanson, E.J. and P.J. Breen. 1985. Effects of fall boron sprays and environmental factors on fruit set and boron accumulation in 'Italian' prune flowers. J. Amer. Soc. Hort. Sci. 110: 389-392.
13. Kelley, J.R. 1980. An analysis of the effects of boron and plant growth regulators on flower development in filbert, Corylus avellana L. M.S. Thesis. Department of Horticulture, OSU, Corvallis, Oregon.
14. Schuman, G.E., A.M. Stanley, and D. Knudson. 1973. Automated total nitrogen analysis of soil and plant samples. Soil Sci. Soc. Amer. Proc. 37: 480-481.
15. Stebbins, R.L. 1977. New information on foliar feeding of tree fruits and nuts. Proc. Ore. Hort. Soc. 68: 92-94.
16. Yogaratnam, N. and D.W.P. Greenham. 1982. The application of foliar sprays containing nitrogen, magnesium, zinc and boron to apple trees. I. Effects on fruit set and cropping. J. Hort. Sci. 52: 151-158.

Chapter 4

REPRODUCTIVE DISORDERS IN HAZELNUTS (Corylus avellana L.)

Abstract

'Barcelona', the principle cultivar of hazelnut in the United States suffers from 3 reproductive disorders which reduce yield; brown stain (BS), nut shriveling and seedlessness (blanks). Brown stain first appears as spots or streaks on the shell in the last week of June and continues to occur until the 2nd week of Aug. Internal tissues become brown and watery and kernels may abort. The incidence of BS varied considerably from year-to-year, e.g. 12% in 1982, 45% in 1983, 6% in 1984, and 0.1% in 1985. Shriveling of nuts was severe in 1984 (33%) but not in 1985 (8%). The percentage of blanks also varied from 6% (in the high set orchard) to 16% (in the low set orchard) in 1984 whereas both the high and low set orchards had 14% blanks in 1985. Following B sprays there was a slight but significant reduction in BS, nut shriveling, and blanks. Although low B content in pith tissues was negatively correlated with BS, low B may be an effect rather than a cause of BS.

Introduction

'Barcelona', the major hazelnut (filbert) cultivar in the United States, is subject to 3 reproductive disorders which reduce yields; brown stain (BS), nut shriveling, and blanks (seedless nuts). The incidence of each disorder varies considerably with years and with orchards. Affected nuts drop prematurely unless they are associated with one or more normal nuts in a cluster.

Brown stain has been observed since 1909 in Oregon, the major center of hazelnut production in the U.S. Losses vary from negligible to an estimated 50% of the crop. Since Miller (13) was unable to find pathogens associated with affected nuts, it has been speculated that BS may be a physiological disorder associated with specific climatic factors. Preceding a serious outbreak in 1969, Lagerstedt observed a heat wave followed by a rainy period. However, the following year he failed to induce BS by modifying temperatures, moistures, and CO₂ levels (11). The most serious outbreak was in 1983 when it was cool and rainy in the spring. In 1984, similar weather conditions prevailed, yet BS was very low. In Spain, more BS was observed when high moisture and high temperature conditions existed (J. Mena & J. Tacias, personal communication). Thus, there is no conclusive evidence about specific climatic factors causing BS. In Oregon, Stebbins (21) observed more BS in well-managed orchards than in those that received little or no attention; however, the reverse was reported in Spain (J.Mena & J. Tacias, personal communication). Some

growers believe that feeding by the obliquebanded leaf roller (OBLR) (Choristoneura rosaceana Harris) causes the stain. Although similar in appearance, OBLR damage and BS can be distinguished (4). Insect-damaged nuts had punctures, excreta, and/or larvae either on the surface or within the nut. Thus, the cause or causes of BS are still unknown.

Brown stain is a genotype-specific disorder. In Oregon, 'Barcelona' is the most severely affected. Other cultivars have relatively little (Gem, Lansing, Summerland) or none at all (Butler, Daviana, Duchily) (21). In France, 'Barcelona' was the cultivar most susceptible to BS (E. Germain, personal communication). In Spain, Pauetet and Gironell cvs. were susceptible to BS and the incidence ranged from 10 to 60% (J. Mena & J. Tacias, personal communication).

Shriveling of developing nuts, which may reduce yield considerably, has not been previously reported. Nut shriveling disorder is associated neither with a lack of pollination and fertilization nor is it influenced by the previous crop load.

Blanks, nuts without well developed kernels, occur every year and their frequency varies with the season, location, and genotype (12,17). Blanks result either from failures of fertilization or embryo abortion (22,23). The amount of blanks is influenced by cultural practices, such as tillage and irrigation (25) but not by NPK and Mg fertilization (17).

Boron is necessary for normal reproductive growth and development in plants. In 1939, Holley and Dulin (7) reported that

B was essential for flower-bud development. They suggested that the amount of B sufficient for normal vegetative growth might be insufficient for flowering in cotton. For normal flower development and seed production in Alsike clover the amount of B required was higher than that needed for vegetative growth (14). In pear trees, when B was insufficient it caused blossom blast (1,9). The severity of this disorder varied with the cultivars, season, orchards, trees, and even limb to limb of a tree in the same orchard. In all affected trees fruit set was reduced greatly. Under B deficiency, various disorders of reproductive tissues have been reported; production of exudates, which became brown later, formation of gum pockets, deformation and shriveling of fruit, abscission of flowers and fruits, development of poor and small seeds, abortion of seeds, and reduction in fruit set (5,6,10,18,24). It has been demonstrated that B is associated with fruit disorders and deformation in apple (3), strawberry (15), and papaya (24). Since the symptoms and the occurrence of the hazelnut reproductive disorders presented in this paper had some similarity with B deficiency symptoms described above, we investigated the possible relationship of B and other mineral elements to these disorders.

Materials and Methods

Brown stain (BS)

The frequency of BS was determined for 4 years in 'Barcelona' orchards (16 orchards in 1982 and in 1983, 43 in 1984, and 54 in 1985) in Oregon's Willamette Valley. One thousand nuts per orchard were randomly sampled during the first 2 years. Since a smaller sample size was found to be adequate, only 200 - 300 nuts in each orchard were sampled in 1984. Because there were very few stained nuts in 1985, 1200 nuts per orchard were sampled.

To study the occurrence of BS through the season in one Corvallis orchard, 300 to 400 nuts were randomly picked from trees weekly from 9 July to 5 Sept., 1983, and at each collection date the percentage of BS calculated. Also, all dropped nuts from a block of 78 trees were collected weekly. At each collection date, the internal structure of 50 dropped BS nuts was compared to that of 50 normal (NR) nuts. Shriveling of nuts, discoloration of pith-like internal tissue (inner ovary wall) and vascular strand, and length and weight of kernels were recorded. Mature nuts were harvested from the ground on 15 Oct. and dried to a 6 to 8% moisture content. Three sets of 100 nuts from both NR and BS lots were cracked to record blanks (empty nuts), aborted embryos (underdeveloped kernels), and normal kernels.

For tissue analyses in 1983, from each of 16 orchards, 200 to 300 nuts were collected during the 3rd week of July and 40 mid-shoot leaves were sampled between the 2nd and 3rd week of Aug. Nut

tissues were separated into the shell (outer ovary wall), the "pith" (inner ovary wall), and the kernel. Leaves and shells were washed in a solution of 10 g EDTA (Ethylenedinitrilo tetraacetic acid, disodium salt) and 10 g Alconox in 20 liters of distilled water, then rinsed 2 times with tap water and once with distilled water. All leaf and nut tissues were dried at 70° C for 48 hours, then ground in a Willey Mill (20 mesh screen). Plant tissues were analysed for P, K, Mg, Ca, S, Mn, Fe, Cu, B, and Zn by ICP emission spectroscopy (8) after dry ashing at 500° C and dissolved in 5 ml of 20% HNO₃, which was diluted to 5% before analysis. Nitrogen was determined colorimetrically after standard micro-Kjeldahl digestion (20). To determine if mineral levels of vegetative and reproductive tissues were related to the incidence of BS, correlation coefficients were calculated for all elements in leaves, and in the shell, "pith", and kernel tissues of both BS and NR nuts.

In 1984, BS and NR nuts were sampled from 5 orchards in the 4th week of July. This delay was due to the paucity of BS nuts this year. Because, in 1983, the correlation between BS incidence and tissue minerals, especially B, was highest in pith, only "pith" tissues were analyzed in 1984. To determine the seasonal trend of minerals in "pith", this tissue was analyzed from nuts collected on 29 June and 5 Aug., 1985.

The possible effect of supplemental B on BS was investigated. In 1984, a total of 840 nut clusters were counted and tagged in an orchard used for fruit set studies. For unsprayed controls, 300

and 600 ppm B-sprayed trees on 20 Oct., 20 April, or 11 June, 120 clusters were tagged in the 1st week of June before BS was evident. These clusters, which included a total of 1990 nuts, were observed weekly for BS until mid-Aug. Since BS nuts were very few in the tagged clusters the percentage of BS was also calculated in nuts harvested from B-sprayed and from control trees. In 1985, B (600 ppm) was sprayed on 13 May and BS was recorded on 400 tagged clusters (200 each from controls and B-treated trees) from 22 June to 10 Aug.

Nut shriveling

In 1983, defective nuts, which differed from BS, were observed in orchards when samples were taken for BS counts; they were shrivelled and discolored. Both in 1984 and 1985, clusters tagged for BS were also observed for nut shriveling and the percentage of such nuts was calculated.

Blank nuts

To see if B applications affected blanks (nuts without a kernel or with less than a half-developed kernel), nuts without BS were randomly sampled from the harvested lots both in 1984 and 1985. Blank counts were made in 2 orchards, one with a high cluster set and another with a low set. In each orchard in 1984, there were 5 replications of 100 nuts each for controls and for B-treated trees. For greater accuracy in 1985 the number of replications was increased to 10 and a total of 4000 nuts were cracked.

Results and Discussion

Incidence of brown stain and its effect on nut drop

The earliest date that BS was observed in 1984 was 23 June. BS appeared first as yellowish brown, brown, or dark brown spots (Plate 4.1) or streaks (Plate 4.2) on the nut shell. Initially, the exudate (Plate 4.1 left) was light in color but following exposure to the environment it became brown or dark brown (Plate 4.1 right), probably as a result of oxidation of the exudate. In many cases, the stained liquid had run down the shell (Plate 4.2 lower right) to form a streak. In BS nuts that dropped prematurely, the normally white internal "pith" tissue (inner ovary wall) became brown and watery (Plate 4.3). The browning started near the shell and moved in towards the kernel. Later the vascular strand, that supports the embryo, turned brown, first at the base, then extended gradually to the kernel (Plate 4.4). Finally the kernel also became brown and aborted (Plate 4.4 lower right). Scanning electron micrographs of NR and BS "pith" tissues show the disintegration of cells in BS nuts (Plate 4.5).

The incidence of BS varied considerably from year to year; there was 12% in 1982, 45% in 1983, 6% in 1984, and 0.1% in 1985 (Table 4.1). In 1983, the most severe year, there was large orchard-to-orchard variation; among 16 orchards BS ranged from 13 to 84%. However, in 1985, a year of minimal BS, among 54 orchards the percentage ranged from 0 to 1.5%. Tree age may account for part of this variability. Younger orchards, 3 to 6 years old, had

less BS and relatively less variation than orchards over 15 years of age (Table 4.1). For example, BS in trees under 6 years ranged from 6% to 10% in 1982, 13% to 38% in 1983, and 0% to 3% in 1984. By contrast BS in trees older than 15 years ranged from 6% to 40% in 1982, 24% to 84% in 1983, and 0% to 25% in 1984. In all 4 seasons orchards with the older trees had 2-fold, or more, BS than orchards under 6 years. Within the same aged orchards, year-to-year variation in BS counts was recorded. One orchard had 4% BS in 1982 and 52% in 1983, while another orchard of the same aged trees in the same locality had 11% BS in 1982 and 35% in 1983. Thus, within the same tree age BS incidence varied between orchards and between years.

The orchard-to-orchard variation may also be associated with cultural practices. Our observations support this hypothesis in some orchards, e.g. one well-cared-for orchard had the highest BS in 1982 (40% BS) as well as in 1983 (84% BS). Stebbins (21) also reported that well-maintained orchards had a higher percentage of BS nuts than the poorly-managed orchards. However, in Spain, good orchards had less BS than the orchards in poor or stressed conditions (J. Mena & J. Tacias, personal communication).

In one orchard, brown stained nuts dropped from the 1st week in July until the 2nd week of Oct., the normal harvest time (Figure 4.1). On each sampling date prior to the normal harvest period, relatively few BS nuts had dropped. For example, the number of BS nuts that dropped per tree was 2 on 9 July, and 13 on 8 Aug. The accumulated preharvest BS drops accounted for 5% of

the total nuts on the tree. At the normal harvest there were 173 BS nuts/tree, i.e. 15.5% of the nuts. BS nuts stayed on the tree because either they were attached to normal nuts in a cluster or BS occurred after the kernels were relatively well-developed. In this orchard, on the first collection date, 9 July, there was 10% BS nuts. The incidence increased to 24.8% by 15 Aug., after which date there was relatively no change (Figure 4.1). The slight difference in percentage of BS between those on the tree and those on the ground at harvest was probably due to some bias in picking BS nuts from trees. Thus, it can be concluded that BS is first seen before 9 July and that factors causing it must be acting from late June to early Aug. In 1984, we observed BS nuts as early as 23 June. These results contradict the observation of Miller (13) who reported that the disorder originates in July and remains constant over the season.

Because the mean diameter of NR and BS nuts in every collection was 2.3 cm, we can conclude that the disorder first appears on full-grown nuts just before shell hardening. Shells of dropped BS nuts in the first collection (9 July) had not yet hardened whereas shells of those collected after the 2nd week of July were mostly hard.

Effects of BS on kernel growth

Dropped BS nuts had smaller kernels than NR nuts. Of the total BS nuts that dropped prior to harvest, 92% had aborted kernels (1 mm to 6 mm long). By 22 Aug. only a few kernels had attained 11 mm, whereas kernel length in 80% of the NR nuts was

12 to 21 mm by this date. However, kernel length in most BS nuts collected from the trees on 9 July, 1 Aug., and 8 Aug., was comparable to that of NR nuts. Apparently these nuts were affected with BS later in the season after the kernels had developed. In NR nuts, mean kernel length doubled from 9 July to 25 July, after which date it remained the same. The 42-fold increase in normal nut weight between 9 July (5 g/100 kernels) and 22 August (204 g/100 kernels) reflected the increase in diameter of kernels and accumulation of storage materials. Of the BS nuts collected at harvest, 21% were blanks, 12% had poorly developed kernels (Plate 4.5), and the remaining kernels (67%) were almost full-sized (1.42 g in BS vs. 1.56 g in NR kernels, dry weight basis). Thus, in our harvest sample of BS nuts 67% would have been marketable. Blemishes on the shells were unsightly. Kernels were slightly less developed directly under the shell where BS was seen, which accounted for the reduction in weight. In orchards with much higher incidence, much greater losses were incurred. Of the NR nuts collected at harvest, there were 11% blanks and 4% underdeveloped kernels.

Mineral contents in the shell, "pith", and kernel tissues of BS and NR nuts

Of 11 minerals analysed N, P, K, S, Fe, Cu, and B levels were significantly different in some BS and NR tissues (Table 4.2). In 1983, "pith" tissues in BS nuts were significantly higher in N, P, K, S, and Cu, while Fe and B were lower than in NR nuts.

Similarly in 1984, BS "pith" tissues were higher in N, S, and Cu and were lower in B and Fe than NR "pith" tissues. In 1985, the levels of these minerals in NR "pith" tissues were similar to those in 1983. However, in 1984, N, P, and K were higher and Fe was lower than in the other 2 years. In 1984, differences in N, P, K, and Fe content in "pith" tissues between BS and NR nuts were low. This was because the "pith" tissue in BS nuts had not disintegrated as much as in 1983.

In a given year mineral composition of "pith" tissue is seasonally influenced as it is in leaves. For example in leaves, as the season progresses N, P, K, S, and Cu decreased while Ca, Fe, and B levels increased (Appendix XII). Similar seasonal trends were observed for some elements in "pith" (Table 4.3). For example, P and K levels in the NR "pith" declined significantly from 29 June to 5 Aug. while S, Ca, Fe, Cu, B, and Zn increased significantly during this period. Because of the breakdown in BS "pith" tissues movement of minerals into or out of the tissue was obviously altered. Therefore, it can be concluded that the relatively low levels of B and Fe in BS "pith" resulted from a failure in the normal translocation into the nut. Also, the normal seasonal decline of N, P, K, and S failed to occur and thus these elements were relatively high in BS "pith". Therefore, it is important to consider the seasonal pattern of mineral content in order to isolate the cause and effect relationship in B- or other mineral-associated disorders. In other BS tissues, N in the shell and both N and Cu in the kernel were significantly higher

than in normal tissues.

Correlation between BS and mineral content of nuts

Correlations between the percentage of BS in an orchard and the levels of 11 mineral nutrients in leaves, shells, "pith", and kernels were rarely significant (Table 4.4). Pith B ($r = -0.57^*$) and kernel B ($r = -0.51^*$) of BS nuts were correlated with BS incidence in each orchard. However, there was no relationship between the incidence of BS and B levels in "pith" or kernels of normal nuts in the same orchard. Phosphorus in the shells of stained nuts ($r = 0.55^*$) was positively correlated with the incidence of the disorder, whereas K ($r = -0.50^*$) and Ca ($r = -0.53^*$) in normal shell were negatively correlated.

Boron content in the "pith" tissue of BS nuts in orchards which had 60% BS or more was significantly lower, 46 ppm B, than in those with 40% or less BS, 58 ppm B (Table 4.5). In general, orchards with greater differences in "pith" B content between NR and BS nuts showed a higher BS incidence. This is because the onset probably occurred earlier and nuts were more disintegrated. That low B did not cause BS was further supported by the fact that high BS orchards did not contain low B in NR "pith" tissues. For example, in 1983, two orchards, one with 20% BS and another with 84% BS, both had 76 ppm B in NR "pith" collected during the 3rd week of July. In 1984, "pith" B levels in NR nuts collected in the 4th week of July were 87 ppm in an orchard with 3.7% BS, 121 ppm with 24% BS, and 76 ppm with 25% BS, the highest incidence in the year.

Effects of foliar B applications on BS incidence

In one orchard that was treated with foliar B sprays for fruit set studies in 1984, control trees had 3.7% BS nuts and B-treated trees had 2.0%. Two levels of B concentrations and time of sprays did not affect BS incidence. The incidence of BS was too low in this orchard to draw any conclusion about the effect of B sprays on BS. Further experiments in a year of high BS are necessary in order to determine if B supplements will reduce this disorder.

Comparision between epicarp lesion and BS disorder

The possibility that insect injury, other than OBLR, causes BS can also be considered. Feeding by certain species of the true bugs in the order Hemiptera causes epicarp lesions (dry sunken tissue with darker zones with necrotic spots) on pistachio nuts (2,19). However, the staining of hazelnuts is different from pistachio lesions in that BS nuts display dark brown liquid oozing out of the shell, while internal tissues are brown and watery. Affected areas were not sunken as in pistachio. Additionally, BS appeared throughout the season even after shells hardened which may be assumed to be too difficult for piercing - sucking insects to penetrate it. However, possibilities of insect damage should not be overlooked and controlled caging experiments are also suggested.

Nut shriveling and B sprays

Developing nut clusters were tagged for BS counts but

shrivelled nuts appeared instead. Shriveling of nuts has not been reported previously. Shrivelled nuts (Plate 4.6) had brown discoloration first at the base which then extended towards the apex. As a result, affected nuts became brown, shrivelled, dried, and dropped prematurely unless they were attached with one or more normal nuts. In some cases shriveling also began at the base. The number of shrivelled nuts varied through the season. Of 1990 tagged nuts, there were 60 shrivels on 23 June (first observation), 460 on 30 June, 624 on 7 July, and 656 on 14 July. This accounted for 33% of the total nuts. After 7 July, very few additional nuts were shrivelled. In 1985, only 40 of 500 nuts were shrivelled by the 2nd week of July, after which date there were no additional shrivels observed. Therefore, nut shriveling occurred between 23 June to 14 July in a low BS year before nut shells became hard.

Applications of 300 ppm B sprays on 20 April, and 11 June reduced defective nuts. The number of shrivelled nuts was 76/301 (25%) in controls, 52/293 (18%) following the April spray, and 38/265 (14%) following the June spray. The rate of 600 ppm B reduced shrivels (22%), but not significantly from controls. In 1985, the percentage of shrivelled nuts was 8% in controls and 6% in B-treated trees. The maximum number of nuts were shrivelled during the rapid nut growth period when increases in fresh weight of normal nut was over 9-fold, from the 2nd week of June to the 1st week of July. Factors inducing this disorder are not known. However, our results indicated that the crop load was not a

factor, since the high crop year (1985) had much lower shrivels than the previous low crop year. Further studies are necessary to determine possible cause(s) of this disorder.

Blanks and B sprays

The percentage of blank nuts varied with orchards and with years. In 1984, one orchard had 16% blanks, which was significantly higher than in another (6%); whereas in 1985, both orchards had 14% blank nuts. Painter (17) also found variation in percentage of blanks between different 'Barcelona' orchards in the same year ranging from 6 to 42% in 1954, 6 to 22% in 1955, and 10 to 45% in 1956. Compared to these figures, the percentage of blanks in the present study was relatively low.

In 1984, B sprays did not significantly reduce blanks (11% in controls and 8% in B-treated trees). However, in 1985, B sprays did significantly lower blanks by 29%, i.e. from 14% in controls to 10% in B-treated trees. Because 1985 was a heavy crop year there may have been a heavier demand for B; thus, foliar B applications in May could have contributed to more normal embryo growth. Painter (16) also reported that borax applied to soil reduced blanks, albeit numbers were very low (2.1% on B-treated trees vs. 4.3% in controls).

Three reproductive disorders of hazelnut have been described in this paper. The seasonal variation in incidence of BS, nut shriveling, and blanks indicate that all these disorders are not necessarily severe in the same year. In 1983, BS was highest and

it caused about 50% crop loss. In 1984, nut shriveling was the most serious problem causing 33% of nuts in one orchard. Hence, it is suggested that further studies on mineral nutrition and other possible causative factors associated with these disorders be investigated to alleviate these disorders in hazelnut orchards.

Table 4.1. Percentage of brown stain (BS) in 'Barcelona' hazelnut orchards during 4 years as related to tree age.¹

Tree age (years)	1982		1983		1984		1985	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
3 to 6	6 - 10	8.0	13 - 38	26.3	0 - 3	2.0	0 - 0.8	0.1
7 to 14	4 - 13	8.4	29 - 67	50.0	0 - 18	4.9	0 - 1.1	0.1
15 or more	6 - 40	19.1	24 - 84	60.0*	0 - 25	11.2*	0 - 1.0	0.1
overall mean		11.8		45.4		6.0		0.1

* Significant at 5% level, LSD values were 29.1 (1983) and 8.1 (1984).

¹Number of orchards surveyed were 16 in each of 1982 and 1983, 43 in 1984, and 54 in 1985.

Table 4.2. Mineral contents of the shell, "pith", and kernel of brown stained (BS) and normal (NR) nuts of 'Barcelona' hazelnuts.

Tissue	N	P	K	S	Fe	Cu	B
1983 (July 17 -23)							
Shell							
BS	0.48	0.07	0.32	0.04	29.8	5.4	9.2
NR	0.24	0.03	0.18	0.02	17.2	4.0	7.7
"Pith"							
BS	2.49**	0.28*	1.88**	0.25**	133.9	15.6**	52.3
NR	1.22	0.17	1.35	0.21	177.3**	10.6	75.2**
Kernel							
BS	4.81**	0.56	1.55	0.15	111.5	18.5**	27.0
NR	3.79	0.51	1.41	0.13	92.5	10.6	25.1
1984 (July 25 -31)							
"Pith"							
BS	3.90*	0.35	3.63	0.37*	86.1	14.0**	61.9
NR	3.42	0.33	3.61	0.34	95.1*	11.7	81.9**

N, P, K, and S are expressed on percent dry weight and Fe, Cu, and B are on ppm (dry weight basis).

Table 4.3. Seasonal changes in mineral content in the "pith" tissue of normal nuts in 1985.

Dates	N	P	K	S	Ca	Mg	Mn	Fe	Cu	B	Zn
6/29	1.36	0.24	1.87	0.16	0.20	0.21	54	59	7	23	19
8/05	1.33	0.13	1.06	0.27	0.85	0.23	62	224	11	65	48
F-test	NS	**	**	**	**	*	*	**	*	**	**

NS denotes non significant at 5%, while * and ** significant at 5% and 1%, respectively.

Table 4.4. Correlation coefficients (r-values) between the incidence of BS and mineral nutrients of various tissues in hazelnuts.

Brown stain vs. Elements	Nut tissues			
	Shell (NR)	Shell (BS)	"Pith (BS)"	Kernel (BS)
Phosphorus	- 0.24	+ 0.55*	+ 0.18	- 0.17
Potassium	- 0.50*	+ 0.39	+ 0.05	- 0.15
Calcium	- 0.53*	- 0.04	- 0.37	- 0.37
Boron	- 0.04	- 0.03	- 0.57*	- 0.51*

Correlation coefficients between the incidence of BS and mineral elements of leaves, "pith" (NR), and kernels (NR) were not significant at 5% level (*). Other elements that were not significantly correlated with BS were excluded from the table. NR means normal, while BS indicates brown stained tissues.

Table 4.5. Percentage of BS nuts in orchards and B contents in BS nut tissues, 1983.

Orchards with BS,%	Type of tissues		
	shell	"pith"	kernel
less than 40	9.5	58.1	29.5
41 to 60	8.8	50.1	25.0
more than 60	9.0	46.6	24.0
LSD at 5%	NS	9.6	NS

NS = not significant within the column at 5% level.

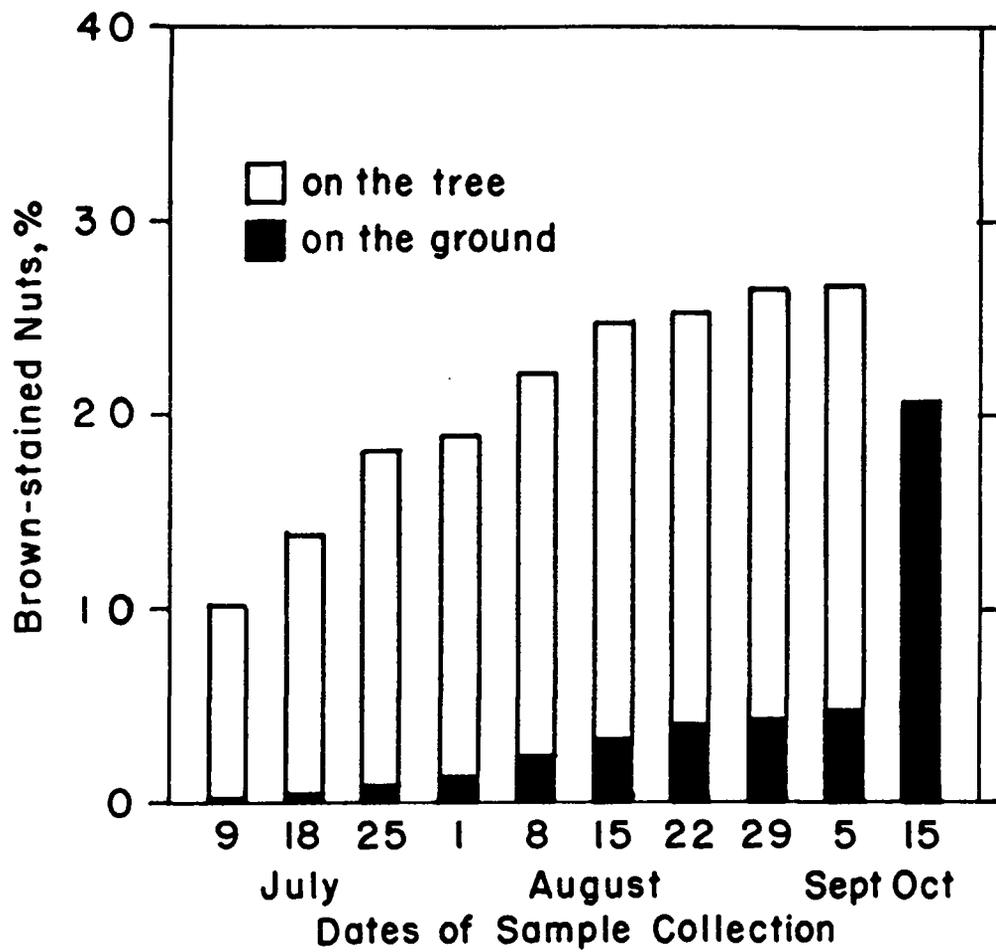


Figure 4.1. Incidence of brown stain and seasonal nut drop in 'Barcelona' hazelnut orchard.

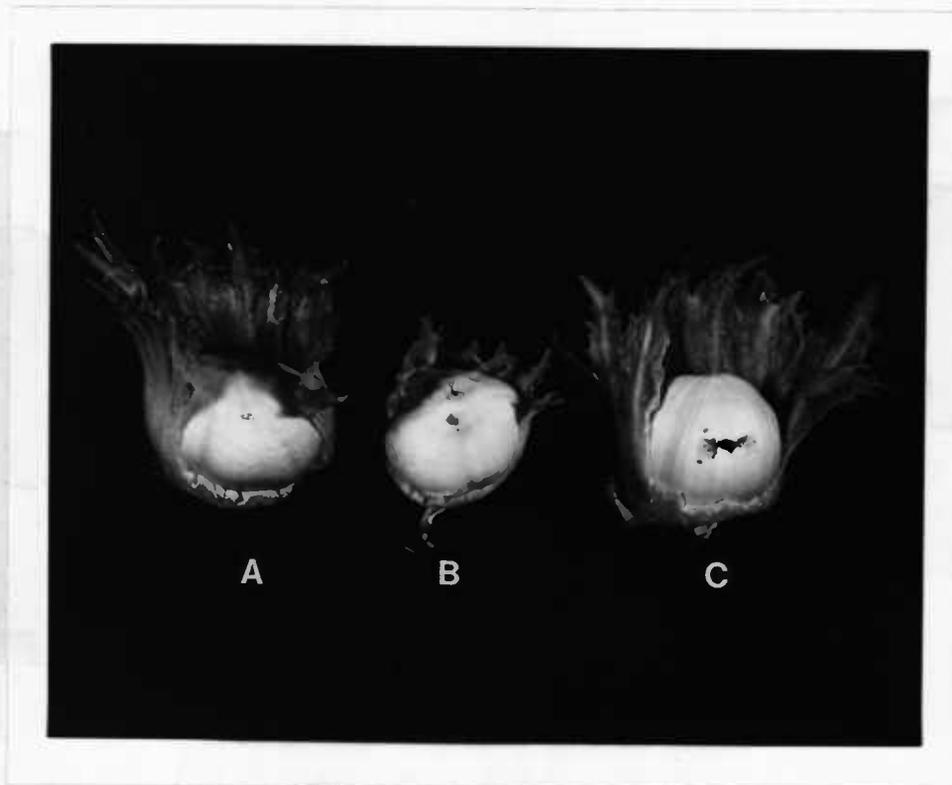


Plate 4.1. Sequential progression of a brown stain spot on the shell.

- A. Clear exudate on the shell.
- B. The clear liquid became darker and yellow.
- C. The exudate, finally, turned brown/dark brown.

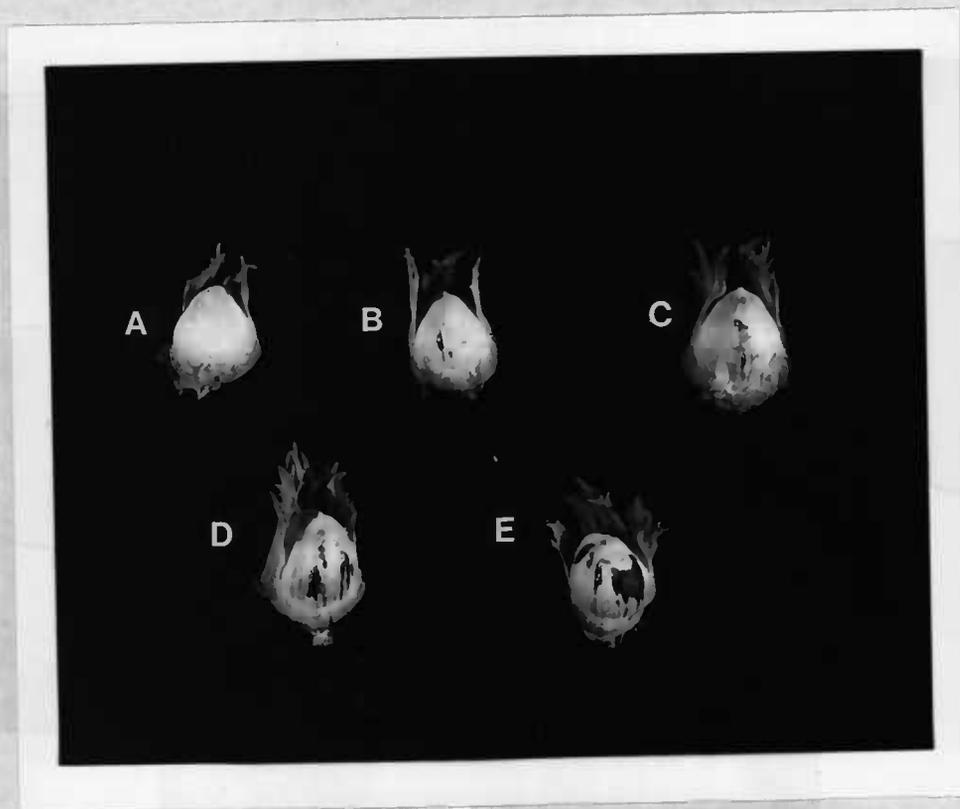


Plate 4.2. Sequential progression of brown stain streaks on the shell.

A. Normal nut with green shell.

B-D. Various stages of BS streaks on the shell.

E. Severely stained nut.



Plate 4.3. Watery "pith" tissue in the brown stain nut.

- A. Brown discoloration at the base.
- B. Brown and watery "pith" tissue, BS occurred before kernel growth started.
- C. Brown and watery "pith" tissue, BS occurred after kernel growth had begun.

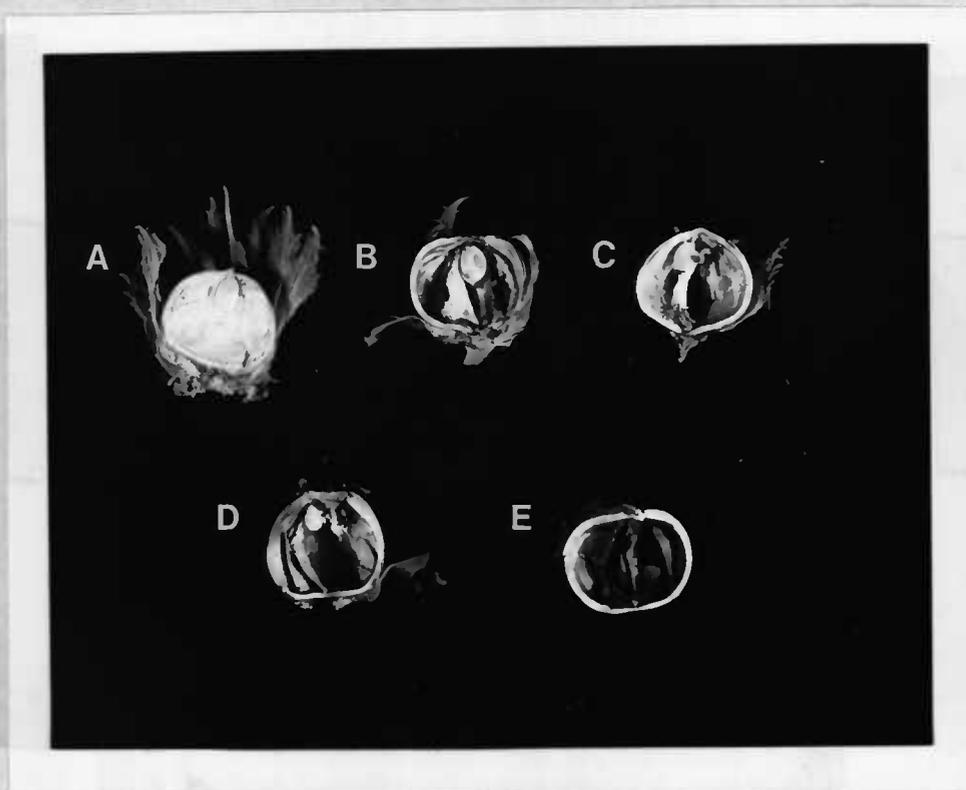


Plate 4.4. Sequential progression in brown discoloration of vascular strand (VS) supporting the kernel.

- A. All internal tissues were white in the normal nut.
- B. BS nut in which discoloration of VS started at the base.
- C. Discoloration of VS almost half the length.
- D. Whole length became brown, but the kernel was still white.
- E. Finally kernel was affected and became a blank nut.

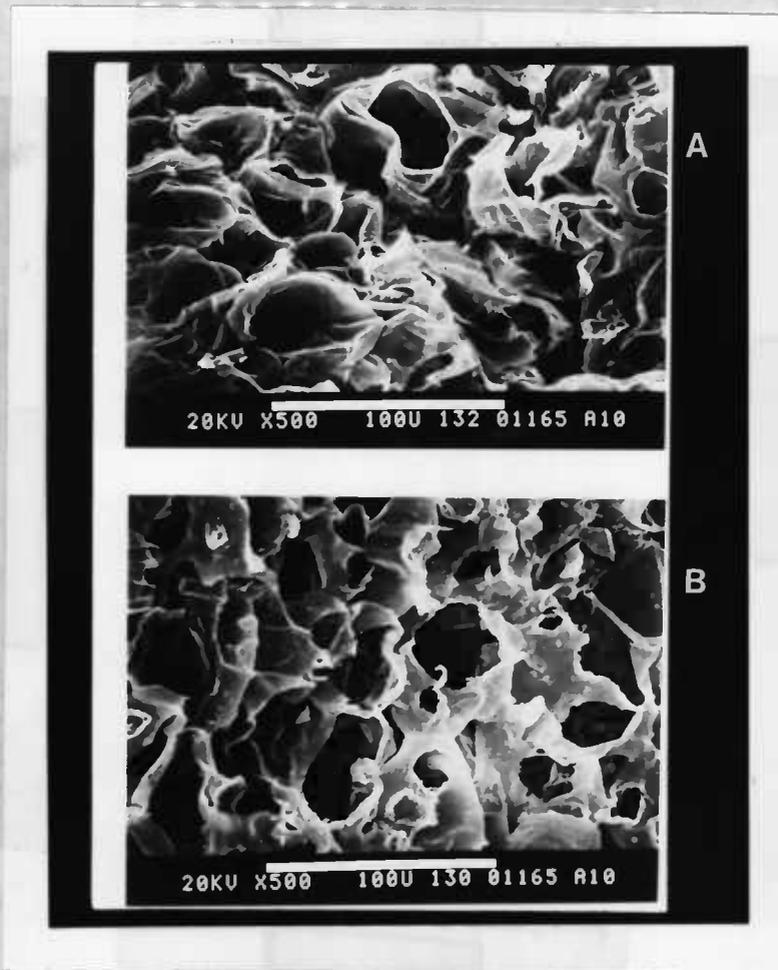


Plate 4.5. Scanning electron micrograph of "pith" tissues.

A. Normal "pith" tissue.

B. Brown stain affected "pith" tissue.

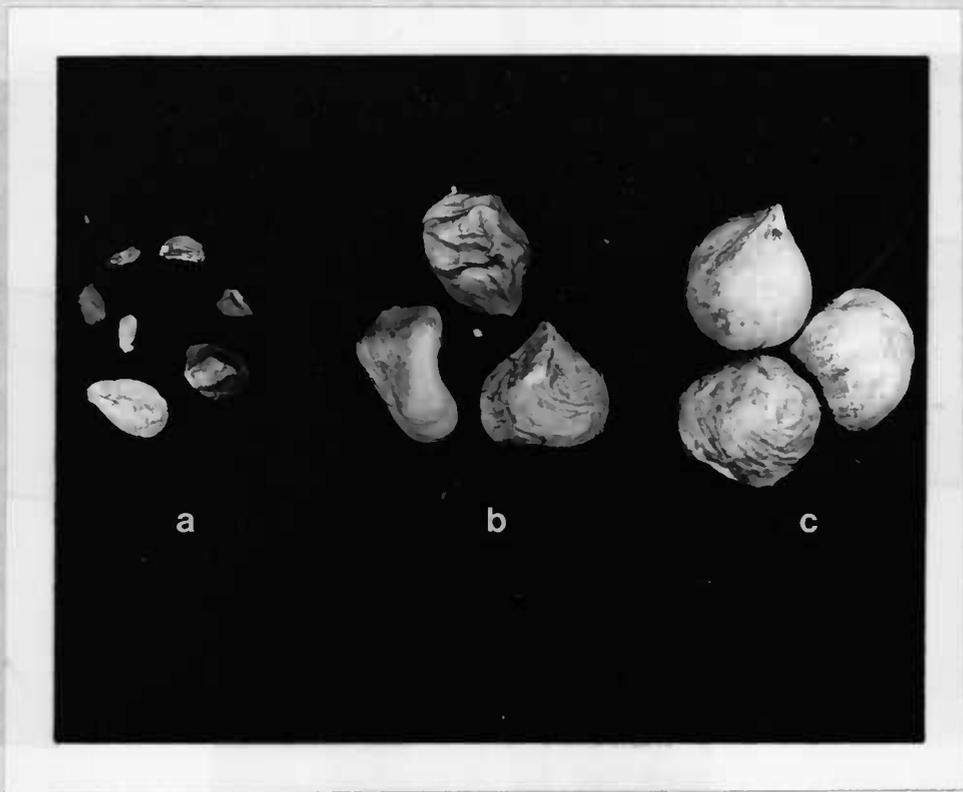


Plate 4.6. Size and shape of kernels in brown stain and normal nuts collected at harvest, 15 Oct. 1983.

- A. Shrivelled and deformed kernels from BS nuts affected early in the season.
- B. Shrivelled and deformed kernels from BS nuts affected late in the season.
- C. Normal kernels.

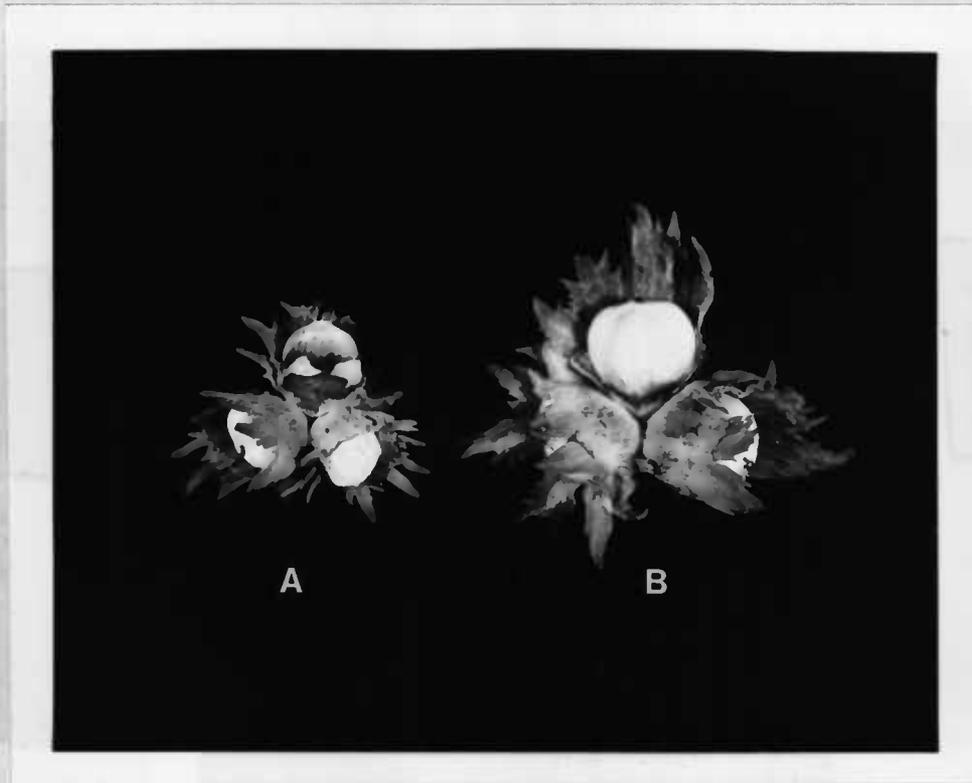


Plate 4.7. Nut shriveling disorder of 'Barcelona' hazelnut;
A. Nut cluster showing symptoms of nut shriveling disorder and
B. Normal nut cluster.

Literature Cited

1. Batjer, L.P., B.L. Rogers, and A.H. Thompson. 1953. 'Blossom blast' of pears: an incipient boron deficiency. Proc. Amer. Soc. Hort. Sci. 62: 119-122.
2. Bolkan, H.A., J.M. Ogawa, R.E. Rice, R.M. Bostock, J.C. Crane. 1984. Leaf-footed bug implicated in pistachio epicarp lesion. Calif. Agri. 38: 16-17.
3. Burrell, A.B. 1936. Boron treatment for a physiogenic apple disease. Proc. Amer. Soc. Hort. Sci., 34: 199-205.
4. Calkin, J. and G. Fisher. 1985. Obliquebanded leafroller and brown stain damage in filberts. Annual Western Orchard Pest and Disease Management Conference, 59: 60.
5. Ganguly, B. 1979. Note on seedlessness in some wheat varieties caused by boron deficiency. Ind. J. Agric. Sci. 49: 384-386.
6. Hansen, C.J. 1958. Boron deficiency in prunes and plums in California. Proc. Ore. St. Hort. Soc. 50: 65-67.
7. Holley, K.T. and T.G. Dulin. 1939. Influence of boron on flower-bud development in cotton. J. Agri. Res., Wash. D.C. 59: 541-545.
8. Issac, R.A. and W.C. Johnson. 1985. Elemental analysis of plant tissue by plasma emission spectroscopy: Collaborative study. J. Assoc. Off. Anal. Chem. 68: 499-505.
9. Johnson, F., D.F. Allmendinger, V.L. Miller, and D. Polley. 1955. Fall application of boron sprays as a control for

- blossom blast and twig dieback of pears. *Phytopath.* 45: 110-114.
10. Kamali, A.R. and N.F. Childers. 1970. Growth and fruiting of peach in sand culture as affected by boron and a fritted form of trace elements. *J. Amer. Soc. Hort. Sci.* 95: 652-656.
 11. Lagerstedt, H.B. 1973. Studies on spacing, training, and cultural practices of filbert trees - A progress report. *Proc. Nut Growers Soc. Ore. and Wash.* 58: 71-77.
 12. Lagerstedt, H.B. 1980. Ennis and Butler filberts. *HortSci.* 15: 833-835.
 13. Miller, P.W. 1931. The brown stain disorder of filberts. *Proc. Ore. Hort. Soc.* 23: 165-170.
 14. Montgomery, F.H. 1951. The effect of boron on the growth and seed production of Alsike clover, *Trifolium hybridum* L. *Can. J. Bot.* 29: 597-606.
 15. Neilson, B.V. and G.W. Eaton. 1983. Effects of boron nutrition upon strawberry yield components. *HortSci.* 18: 932-933.
 16. Painter, J.H. 1951. Filbert nutritional experiment. *Proc. Ore. Hort. Soc.* 43: 179-182.
 17. Painter, J.H. 1956. Filbert nuts containing no kernels. *Proc. Nut Growers Soc. Ore. & Wash.* 42: 223-231.
 18. Perez, A. and N.F. Childers. 1982. Growth, yield, nutrient content and fruit quality of *Carica papaya* L. under controlled conditions. II. Boron effects. *J. Agri. Univ.*

- Puerto Rico. 66: 80-88.
19. Rice, R.E., J.K. Uyemoto, J.M. Ogawa, and W.M. Pemberton. 1985. New findings on pistachio problems. Calif. Agri. 39: 15-18.
 20. Schuman, G.E., A.M. Stanley, and D. Knudsen. 1973. Automated total nitrogen analysis of soil and plant samples. Soil Sci. Soc. Amer. Proc. 37: 480-481.
 21. Stebbins, R.L. 1984. What is known about brown stain? Proc. Nut Growers Soc. Ore., Wash. & B.C. 69: 101-108.
 22. Thompson, M.M. 1967. Role of pollination in nut development. Proc. Nut Growers Soc. Ore. & Wash. 53: 31-36.
 23. Thompson, M.M. 1979. Growth and development of the pistillate flower and nut in 'Barcelona' filbert. Jour. Amer. Soc. Hort. Sci. 104: 427-432.
 24. Wang, D.N. and W.H. Ko. 1975. Relationship between deformed fruit disease of papaya and boron deficiency. Phytopathology 65: 445-447.
 25. Zioni, E. 1963. Influence of cultivation and irrigation on the preharvest drop. Quad. Speria. Frutticola Ita. 4: 363-367.

Chapter 5

BORON PARTITIONING IN B-SPRAYED AND UNSPRAYED FRUITING TWIGS OF HAZELNUT.

Abstract

Following B sprays, fruit set increase in 'Barcelona' hazelnut was accompanied by a decrease in dry-matter accumulation for the entire fruiting twig. In unsprayed controls prior to 5 June, leaves constituted 80% of the total dry weight of a fruiting twig. Later in the season (5 Aug.) the percent dry weight was maximum in the nut tissue (66%), followed by leaves (17%), and then husks (13%). Leaves contained 87% of the total B in a fruiting twig early in the season, indicating that the leaf was a major sink for B at that time. Of the net B increases over a 2 months period, 24% was in the leaves, 38% in the nuts, and 37% in the husks. By 5 Aug., compared to other tissues, stem dry matter (3%) and B content (3%) was negligible; hence, the stem was of little importance in overall partitioning. Boron sprays did not alter B partitioning in the fruiting twigs.

Introduction

Boron was first considered essential for normal growth of plants by Agulhon (1). Since then experiments, both in the field and in growth chambers have indicated that under B-lacking or B-excess situations, plants suffer from various vegetative and reproductive irregularities. The B requirement for reproductive growth in plants is higher than that needed for vegetative growth. For example, a higher amount of B was required for flower development and seed production in Alsike clover than for vegetative growth (5). In 'Italian' prune trees, foliar sprays of B increased fruit set even if leaf B was considered adequate (2,3). In hazelnut trees boron sprays generally produced fruit set increases regardless of August leaf B levels (6). This suggests that Aug. leaf levels had little bearing on fruit set. Boron levels in May nuts were more strongly related to relative fruit set than were leaf levels. Partitioning of dry matter and B in fruiting twigs may help explain the relationship between fruit set and B levels in early nuts.

The objectives of this study were to evaluate partitioning of B and dry matter and to determine if B treatments alter the partitioning of B in a fruiting twig.

Materials and methods

Solubor (78% $\text{Na}_2\text{B}_8\text{O}_{13}\cdot 4\text{H}_2\text{O}$ and 20% $\text{Na}_2\text{B}_4\text{O}_7\cdot 5\text{H}_2\text{O}$) spray at 600 ppm B concentration was applied in one Barcelona hazelnut orchard for fruit set studies on 13 May, 1985. The application of B with 300 ppm X-77, a non-ionic wetting agent, was made to the point of drip with a handgun sprayer (9 gal/min, PSI of 200 lbs). Four-leaved fruiting twigs containing 2 nuts/cluster were collected from B-treated and unsprayed control trees on 5 June (early stage) and 5 Aug. (late stage). There were 3 replications for each treatment, and each sample was collected from 3 trees. Leaves, stems, nuts, and husks of these twigs were separated and washed in a solution of 10 g EDTA disodium salt and 10 g Alconox in 20 liters of distilled water. Tissues were rinsed 2 times with tap water and once with distilled water. Fresh weight was recorded before washing and dry weight after tissues were dried at 70°C for 48 hours. The dried tissues were then ground in a Willey Mill (20 mesh screen). Tissues were analysed by modified ICP emission spectroscopy (4) after dry ashing at 500°C and dissolved in 5 ml of 20% HNO_3 , which was diluted to 5% before analysis.

Results and Discussion

Boron treatments significantly decreased the dry weight of a fruiting twig (Figure 1A) although such applications enhanced fruit set in hazelnuts. A 14% increase in fruit set with a B spray was accompanied by decrease in total dry weight of fruiting twigs at both sampling dates (14% on 5 June and 16% on 5 Aug.). This suggests that increases in fruit set may be at the expense of dry matter accumulation in fruiting twigs.

Prior to June, 78% of the total dry matter of a fruiting twig was in the leaves, whereas later in the season, leaf dry weight accounted for only 17% of the total weight. Stem dry matter increased over time, 1.4 g (5 June) to 2.4 g (5 Aug.) (Figure 1A), but the increase was very little relative to that in nut or husk tissues. By 5 August, stem dry matter constituted only 3% of the fruiting twig; hence the stem was of little importance to overall partitioning. Boron sprays did not affect partitioning of stem dry matter. Similarly, compared to other tissues, B content in stems was relatively unchanged over time and of little (3%) importance to overall partitioning.

Leaf tissues contained the highest amount of total B both early and late in the season but the percentage of the total decreased with time, i.e. 87% (prior to 5 June) and 44% (by 5 Aug.) (Figure 1B).

Dry weight of leaves, usually, remained constant over time (Appendix Figure I) but B concentration increased (Table 1). The

increase in total B in untreated leaves during a 2-month period was 376 μg , i.e. from 611 μg to 987 μg (Figure 1B) which accounted for 24% of the net B increase in the fruiting twig. Although the absolute amounts of total B are different, the percentage of the net increase in total B that was accounted for in leaf tissue is similar in B-treated leaves. Boron sprays increased leaf B but did not affect post-spray B partitioning in twig tissues.

Early in the season prior to 5 June, only 3% of the total B was present in the nut tissues, while by 5 Aug. 27% was in the nuts (Figure 1B). Nut dry weight increased faster than nut B input, thus decreasing B concentration (Table 1). In unsprayed nut tissues the increase in dry weight of nuts over time was 50-fold or more (Figure 1A & Appendix Figure I). When B was applied the increase in dry weight was 37-fold. Because of less dry matter B-treated nuts accumulated less B than unsprayed controls (Figure 1). However, 37% and 38% of the net B increase in fruiting twigs could be accounted for in nut tissues for both sprayed and unsprayed treatments.

Dry weight of husks increased slower than husk B input, thus B concentration increased in these tissues (Table 1). The husk dry weight early in the season constituted 6% of the total weight and it increased to 13% later in the season, while husk B content was 3% of the total early B and it increased to 26% later in the season (5 Aug.). By 5 June, following B sprays, the increase in dry weight of husk was similar (0.9 g in unsprayed controls vs. 1.0 g in B-sprayed tissues) but the B content increased (23 μg B

in controls vs. 63 μg in B-treated tissues). 37% of the total net B increase could be accounted for in the husk regardless of B treatment.

Although B treatments substantially increased total B, enhanced fruit set, and decreased dry weight of tissues, there was no difference in the post-spray net B increase between B-sprayed and unsprayed fruiting twigs for either leaf, nut, husk, or stem tissues.

By 5 June, the amount of B added to the fruiting twig after 13 May sprays was 766 μg which accounted for 28% of the total Aug. B in the tissues (2737 μg B). Furthermore, early in the season, the difference between unsprayed and B-sprayed leaf content was 718 μg out of a net difference of 766 μg in the whole twig; hence 94% of the net increases attributed to B sprays was found in leaves, less than 1% in nuts and 5% in husks. Even though only a small portion of sprayed B can be accounted for in early nut tissues, the total B content of young nut tissue was substantially increased, 41% (from 16.1 μg to 22.7 μg), compared with unsprayed tissues. This increase may be important in enhancing fruit set especially in view of the lack of a usable relationship between leaf B and fruit set (6).

Table 5.1. Boron concentration (ppm) in different parts of a fruiting twig of 'Barcelona' hazelnuts at two sampling dates in 1985.

Parts of	5 June		5 August	
	Control	+ boron	Control	+ boron
Leaves	46.3	123.3**	85.7	164.3**
Stems	36.7	41.7	30.3	33.0
Nuts	18.3	22.0	13.3	13.0
Husks	24.7	63.3**	62.0	68.7

**Significant at 1% level. 600 ppm B was applied on 13 May.

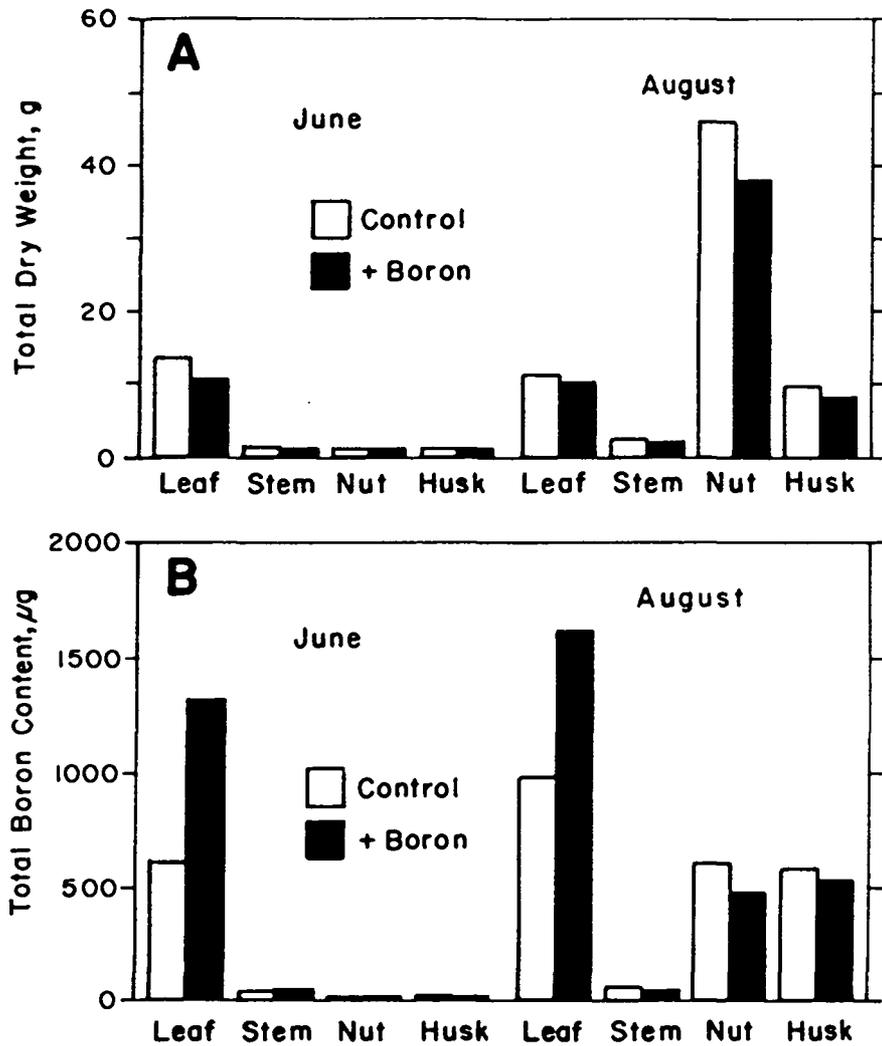


Figure 5.1. A comparison between control and 600 ppm boron-sprayed fruiting twigs in relation to the partitioning of dry weight and boron in the leaf, stem, nut, and husk of 'Barcelona' hazelnuts at 2 sampling dates:

A. Dry weight, g. B. Boron content, µg.

Literature Cited

1. Agulhon, H. 1910. Emploi du bore comme engrais catalytique (The use of boron as catalytic fertilizer). Compt. Rend. Acad. Sci. (Paris), 150: 288-291.
2. Callan, N.W., M.M. Thompson, M.H. Chaplin, R.L. Stebbins, and M.N. Westwood. 1978. Fruit set of 'Italian' prune following fall foliar and spring boron sprays. J. Amer. Soc. Hort. Sci. 103: 253-257.
3. Hanson, E.J. and P.J. Breen. 1985. Effects of fall boron sprays and environmental factors on fruit set and boron accumulation in 'Italian' prune flowers. J. Amer. Soc. Hort. Sci. 110: 389-392.
4. Issac, R. A. and W.C. Johnson. 1985. Elemental analysis of plant tissue by plasma emission spectroscopy: Collaborative study. J. Assoc. Off. Anal. Chem. 68: 499-505.
5. Montgomery, F.H. 1951. The effect of boron on the growth and seed production of Alsike clover, Trifolium hybridum L. Can. J. Bot. 29: 597-606.
6. Shrestha, G.K., M.M. Thompson, and T.L. Righetti. 1986. Foliar-applied boron increases fruit set in 'Barcelona' hazelnut. (Submitted to the J. Amer. Soc. Hort. Sci.).

Chapter 6

GENERAL DISCUSSION AND CONCLUSIONS

Fruit set studies were conducted for 2 years in hazelnut orchards containing different levels of B in the previous August leaves. Fruit set varied with years and with orchards. In 1984, the overall mean set was 30.5% for the unsprayed controls, while in 1985 it was 49.1%. Between orchards there was a big difference in set. For example, in 1985, controls in one orchard had 37.5% set while in another it was 63.1%. The fruit setting process is a complex and multidimensional phenomenon and many factors can affect set (63). Factors contributing to differences in set include cultural practices, crop load, tree vigor, pruning, mineral nutrition, hormonal balance within the tree, and pests and diseases.

When B was foliar sprayed, fruit set was increased over controls in all orchards in both years, although increases in every orchard were not always significant. Using pooled data from 4 orchards in 1984, one spray of 300 ppm or 600 ppm B applied during mid-May produced a significantly higher set than the controls (Appendix I). Differences in response between these two rates were insignificant. When fruit set was analysed on an individual orchard basis, the 600 ppm B treatment caused significant increases over controls in 1 of 4 orchards in 1984 and 4 of 5 orchards in 1985 (Table 3.1). The limiting factor for fruit set in orchards which showed very little response to B sprays must be something other than B levels in tissues. Between 2 consecutive

years, response to B sprays was high in 1984 (30.5% in controls vs. 39.3% in B-treated trees) when overall set was low but the response was low in 1985 (from 49.1% in controls to 56.5% in B-treated trees) when overall set was high. The results obtained in the present experiments as well as the reports made earlier by Baron (15,16,17) confirm that B sprays help increase fruit set in 'Barcelona' orchards.

Following B sprays B content in female flowers (Appendix VI), leaves, and early nuts increased. Increases in hazelnut set after B sprays could be due to increase in B content in vegetative and reproductive tissues which may enhance metabolic functions favorable to fruit set. Following postharvest B sprays on prune trees Hanson and Breen (115) increased B content in flowers. They suggested that fruit set response after B applications could be associated with increase in B levels in flowers. In the present experiments, fall-applied B sprays significantly increased B content of female flowers over unsprayed controls by 27% with 300 ppm and 56% with 600 ppm spray concentrations (Appendix VII). In 1984, in unsprayed controls in all orchards B levels in hazelnut flowers were similar, 26 to 30 ppm (Appendix VII), but fruit set varied from 22.5 to 36.5% (Appendix V). With B sprays both B content in flowers and fruit set increased. When the correlation coefficient between B content of female flower buds and fruit set was computed, the r value was significant (+0.42*). Hence, the B content of flowers after B sprays may have affected the fruit setting process. However, B levels in nuts early in the current

season appeared to have greater significance to fruit set in hazelnuts than levels in female flower buds, leaves, or nuts collected after May. This is suggested by a higher correlation ($r = .63^{**}$) between May nut B and relative fruit set in this investigation.

Because levels in the previous August leaves had little bearing on fruit set response in hazelnuts, increases in fruit set from B sprays could be a direct effect on the female reproductive system. Chaplin et al. (60) could not predict the B requirement for optimum reproductive growth and fruit set based on traditional mid-summer leaf tissue analysis. They suggested that the increase in yields (fruit set) from B application was due to a direct effect on the reproductive physiology of prune trees. Callan et al. (49) also revealed a similar role of B in fruit set and obtained positive responses from fall-applied B in several prune orchards considered B-sufficient. It is suggested by Chaplin et al. (60) that the applied B in fall moves into the fruit buds where it overwinters and is metabolized into forms readily available for the fruit set process the following spring. Increases in hazelnut set in the present experiments after fall B sprays (Figure 3.1 and Appendix V) could be due to similar metabolic functions occurring in fruit buds as suggested for prune trees.

Three reproductive disorders of hazelnuts which may reduce yields considerably are described. These disorders are brown stain, nut shriveling, and blanks. Although cause(s) of these

disorders are unknown, the severity of BS varied greatly with the season, location, tree age, and orchard maintainance. In Oregon, orchards that had good management had more BS than those that received little care (227a), but the reverse was true in Spain (J. Mena and J. Tacias, personal communication). In 1983 and 1984, similar weather conditions (cool temperatures and high rainfall during spring) prevailed but the BS incidence varied considerably. On the other hand, Mena and Tacias of Spain observed a high incidence in the year of high moistures and high temperatures. Lagerstedt (1973) created artificial environments by modyfying temperatures, rainfall, and CO₂ levels around the hazelnut tree to induce BS; none of these alterations was effective. Hence, no clear-cut relationship to the weather pattern has been established.

Shriveling of developing nuts has not been reported previously. In 1983, hazelnut production was reduced by almost 50% by brown stain, a reproductive disorder which affected nuts from early July to until the natural harvest drop. In 1984 a high crop was expected because of the low crop load in the previous year. However, production in this year was again low. A different disorder, nut shriveling, was observed in one orchard which affected 33% of nuts. If this disorder were also present in other orchards, it could account for the unexpected low yields. For example, in 1982, the total hazelnut production in the United States was 18,900 tons, whereas in 1984, it was 13,400 tons, 29% less than the 1982 crop. In 1985, there was little nut shriveling

and negligible brown stain and the hazelnut production in the United States was higher than ever before. Studies on mineral nutrition, and cultural practices are suggested to find a cause and effect relationship with regard to this disorder.

Seedlessness, or blanks, results from lack of fertilization between male and female gametes, or as a result of embryo abortion later in the season (232a,233). What causes an embryo to abort, or what prevents fertilization between a compatible pollinizer and the main cultivar of this wind-pollinated species is obscure.

It is interesting to note that these disorders start appearing from the 3rd week of June when nut growth and development is most rapid. Boron sprays in mid-May alleviated these 3 disorders partially, but significantly, indicating that the supply of B to the growing nuts from leaves, or other reserves, was perhaps insufficient. These sprays could have met partially the B requirements for normal nut growth.

The following general conclusions can be drawn from this work:

1. Foliar-applied B sprays increased fruit set irrespective of a low or high crop year. The response to B applications was higher in a light-crop year.
2. Concentrations of both 300 or 600 ppm B were equally effective for increasing fruit set; however, the higher rate caused severe foliage damage when sprays were applied in April, when leaves were very small.
3. Benefits from B supplements were attained at a wide range

- of spray timings, but mid-May appears to be the optimum time for applications.
4. August leaf B levels currently being used as a standard for B recommendations have little bearing on set.
 5. Boron requirement for optimum productivity seems higher in this crop than other fruit species.
 6. Boron does not appear to be translocated from leaf to nut.
 7. The real advantage of spring B applications is by direct absorption by the (developing) nuts.
 8. Brown stain incidence varied from year to year and from orchard to orchard.
 9. Low B content in the affected "pith" tissue seems to be an effect rather than a cause of BS.
 10. BS increased the percentage of blanks and reduced the quality of nuts and kernels.
 11. Spring-applied B sprays slightly alleviated BS, nut shriveling, and blanks; however, further studies are necessary to find the cause of these problems.
 12. In a fruiting twig, most B was partitioned in leaves early in the season whereas nuts and husks contained the highest amount of net B increase late in the season.
 13. Application of B in mid-May did not alter B partitioning in leaves, stems, nuts, and husks.

BIBLIOGRAPHY

1. Agarwala, S.C., P.N. Sharma, C. Chatterjee, and C.P. Sharma. 1981. Development and enzymic changes during pollen development in boron deficient maize plant. *J. Plant Nutrition* 3: 329-336.
2. Agulhon, H. 1910. Emploi du bore comme engrais catalytique (The use of boron as catalytic fertilizer). *Compt. Rend. Acad. Sci. (Paris)*, 150: 288-291.
3. Alexander, T.R. 1942. Anatomical and physiological response of squash to various levels of boron supply. *Bot. Gaz.* 103: 475-491.
4. Andrus, C.G. 1955. Brittle stem, an apparently new sublethal gene in tomato. *Tomato Genet. Coop. Rep.* 5: 5.
5. Anic, J. 1972. Appearance of Jonathan apples with severe boron deficiency in an orchard in Medzhimurje. *Agrohemijska (9-12)*: 485-490.
6. Antles, L.C. 1949. Soil chemicals affect potency of pollens. *Better Fruit* 43: 28-29.
7. Antles, L.C. 1951. Eighteen years of commercial pollen research. *Hoosier Hort.* 33: 68-74.
8. Arora, J.S. and J.R. Singh. 1972. Response of guava (*Psidium guajava*) to boron spray. *Engei Gakkai Zasshi* 41: 239-244.
9. Arturo, L.A. 1984. Bud failure and boron levels in tissues of four *Vitis vinifera* L. cultivars. *Agric. Tec. (Santiago)*, 44: 93-94.
10. Askew, H.O. and E. Chittenden. 1936. The use of borax in the control of 'Internal cork' in apples. *J. Pom. Hort. Sci.* 14: 227-245.
11. Askew, H.O., E.T. Chittenden, and R.J. Monk. 1951. 'Die-back' in raspberries - a boron deficiency ailment. *J. Hort. Sci.* 26: 268-284.
12. Axford, M.A., M.N. Westwood, and M.H. Chaplin. 1975. Effects of scion and rootstock on mineral content of leaves of both scions and rootstocks of sweet cherry. *HortSci.* 10: 234-235.

13. Badawi, A.M., A.M. Sweidan, M.A. Fayek, and A.H.I. El-Hawary. 1981. Effect of B, Zn, and Ca on growth, fruit quality and storage ability of Le Conte pear. Research Bulletin, Faculty of Agri., Ain Shams University, No. 1656, 20 pp.
14. Baranova, L.S. 1969. Dynamics of free-amino acids in Barley apical points in connection with boron nutrition. Zapiski Leningradskogo Sel'skokokho Zyaistvennogo Instituta 139: 119-128.
15. Baron, L.C. 1968. Waking up the sleeping giant. Proc. Nut Growers Soc. Ore. and Wash. 54: 22-28.
16. Baron, L.C. 1969. Increasing filbert set or a partial cure for developmental dropouts. Proc. Nut Growers Soc. Ore. and Wash. 55: 52-54.
17. Baron, L.C. 1973. The value of boron sprays on filberts. Proc. Nut Growers Soc. Ore. and Wash. 58: 43-44.
18. Baron, L.C. and R. Stebbins. 1981. Growing filberts in Oregon. Oregon State Univ. Extn. Bulletin, No. 628, 30 pp.
19. Batjer, L.P. and M.H. Haller. 1942. Fruit maturity and growth of apple trees as affected by boron content (Preliminary report). Proc. Amer. Soc. Hort. Sci. 40: 29-30.
20. Batjer, L.P. and B.L. Rogers. 1953. Control of blossom blast on pears in Central Washington. Proc. Wash. State Hort. Assoc. 49: 40-42.
21. Batjer, L.P., B.L. Rogers, and A.H. Thompson. 1953. 'Blossom blast' of pears: an incipient boron deficiency. Proc. Amer. Soc. Hort. Sci. 62: 119-122.
22. Batjer, L.P. and A.H. Thompson. 1949. Effect of boric acid sprays applied during bloom upon the set of pear fruits. Proc. Amer. Soc. Hort. Sci. 53: 141-142.
23. Benson, N.R., E.S. Degman, and I.C. Chmelier. 1961. Translocation and re-use of boron in broccoli. Pl. Physiol. 36: 296-301.
24. Berger, K.C., T. Heikkinen, and E. Zube. 1957. Boron deficiency, a cause of blank stalks and barren ears in corn. Soil Sci. Soc. Amer. Proc. 21: 629-632.
25. Bertrand, G. and L. Silberstein. 1938. Distribution of boron in organs of the White Lily. Compt. Rend. Acad. Sci. (Paris). 206: 796-799.

26. Bertrand, G. and L. Silberstein. 1940. Distribution of boron in the organs of Nicotiana rustica. Compt. Rend. Acad. Sci. (Paris). 210: 70-73.
27. Blaha, J. and J. Schmidt. 1939. The effect of boron on the germination of pollen in fruit trees. Sbor. Cesk. Acad. Zem. 14: 186-192.
28. Blamey, F.P.C., W.J. Vermeulen, and J. Chapman. 1984. Inheritance of boron status in sunflower. Crop Sci. 24: 43-46.
29. Bobko, E.V. 1935. Recherches sur le role du bore dans les plantes. Ann. Agron. 5: 801-803.
30. Bobko, E.V. and V.V. Zerling. 1938. Influence of boron on the reproductive development of plants. Ann. Agron. 8: 174-184.
31. Bohnsack, C.W. and L.S. Albert. 1977. Early effects of boron deficiency on indoleacetic acid oxidase levels of squash root tips. Pl. Physiol. 59: 1047-1050.
32. Bradford, G.R. 1966. Boron in Diagnostic Criteria for Plants and Soils, p. 33-61. (ed) H. D. Chapman, Univ. of California, 1966.
33. Bradley, M.V. and J.C. Crane. 1975. Abnormalities in seed development in Pistacia vera L. J. Amer. Soc. Hort. Sci. 100: 461-464.
34. Bramlage, W.J., M. Drake, and W.J. Lord. 1980. The influence of mineral nutrition on the quality and storage performance of pome fruit grown in North America, p. 29-37. In: D. Atkinson, J.E. Jackson, R.O. Sharples, and W.M. Waller (eds.). Mineral Nutrition of Fruit Trees, Butterworths, London.
35. Bramlage, W.J. and A.H. Thompson. 1962. The effects of early sprays of boron on fruit set, color, finish, and storage life of apples. Proc. Amer. Soc. Hort. Sci. 80: 64-72.
36. Brandenburg, E. 1931. Die herz- und trockenfaule der ruben als Bormangel-Erscheinung. Phytopathologische Zeitschrift, 3: 499-517.
37. Brandenburg, E. 1932. Die herz- und trockenfaule der ruben - ursache und bekampfung. Angewandte Botanik, 14: 194-228.
38. Brink, R.A. 1924. The physiology of pollen. II. Further consideration regarding the B requirements for growth. Amer.

- J. Bot. 11: 283-294.
39. Brown, B.A. and A. King. 1939. Soil conditions under which alfalfa responds to boron. Soil Sci. Soc. Amer. Proc. 4: 310-313.
 40. Brown, J.C. and J.E. Ambler. 1973. Genetic control of uptake and a role of boron in tomato. Soil Sci. Soc. Amer. Proc. 37: 63-66.
 41. Brown, J.C. and W.E. Jones. 1971. Differential transport of boron in tomato (Lycopersicon esculentum Mill). Physiol. Plant. 25: 279-282.
 42. Burrell, A.B. 1936. Boron treatment for a physiogenic apple disease. Proc. Amer. Soc. Hort. Sci. 34: 199-205.
 43. Burrell, A.B., D. Boynton, and A.D. Crowe. 1956. Boron content of apple in relation to deficiency symptoms and to methods and timing of treatments. Proc. Amer. Soc. Hort. Sci. 67: 37-46.
 44. Burstrom, H. 1948. The rate of the nutrient transport to swelling buds of trees. Physiol. Plant. 1: 124-135.
 45. Bussler, W. 1980. Anatomical-histological investigations on plants suffering from micronutrient deficiencies. In: M.M. El-Fouly (ed.). Proceedings of the second workshop on micronutrients and plant nutrition, Cairo, Mondale Press. 25-46.
 46. Busseler, W. 1981. Microscopical possibilities for the diagnosis of trace elements stress in plants. J. Plant Nutrition 3: 115-128.
 47. Cain, J.C. and C.B. Shear. 1964. Nutrient deficiencies in deciduous tree fruits and nuts. In: Hunger Signs in Crops. 3rd edition by H. B. Sprangue. 287-326 pp.
 48. Callan, N.W. 1977. Effect of boron sprays on fruit set, fruit quality, boron distribution, and floral morphology of 'Italian' prune (Prunus domestica L.). Ph.D. Thesis, Hort. Dept., OSU, Corvallis.
 49. Callan, N.W., M.M. Thompson, M.H. Chaplin, R.L. Stebbins, and M.N. Westwood. 1978. Fruit set of 'Italian' prune following fall foliar and spring boron sprays. J. Amer. Soc. Hort. Sci. 103: 253-257.
 50. Calzoni, G.L., A. Speranza, and N. Bagni. 1979. In vitro germination of apple pollens. Sci. Hortic. (Amsterdam), 10: 49-55.

51. Campbell, L.C., M.H. Miller, and J.F. Loneragan. 1975. Translocation of boron to plant fruits. *Austr. J. Pl. Physiol.* 2: 481-487.
52. Carlos, R. 1975. Calcium relationships in vegetable nutrition and quality. *Comm. Soil Sci. Plant Anal.* 6: 289-291.
53. Carpena Artes, O., R. Ruiz Carpena, P. Zorhoza, and G. Collado. 1984. A possible role for boron in higher plants. *J. Plant Nutrition* 7: 1341-1354.
54. Carpena Ruiz, R. and O. Carpena Artes. 1983. Influence of boron on amino acid contents in tomato plants. II. Leaf. *Agrochimica* 27: 506-513.
55. Cerda, A., M. Caro, and F. Santa Cruz. 1982. Redistribution of nutrients in Verna lemon trees determined by an indirect method. *An. Edafol. Agrobiol.* 41:697-704.
56. Chakravarty, S.K., H. Sinha, and K.P. Singh. 1979. Note on boron nutrition of cereals and legumes in a sand culture study. *Indian J. Agric. Sci.* 49: 382-383.
- 56a. Chamel A. and A.M. Andreani. 1985. Demonstration of the penetration of boron in apple fruit using an enriched stable isotope. *HortSci.* 20: 907-908.
57. Chamel, A.R., A.M. Andreani, and J.F. Eloy. 1981. Distribution of foliar-applied boron measured by spark-source Mass Spectrography. *Plant Physiol.* 67: 457-459.
58. Chaplin, M.H. 1972. Fertility trends revealed through foliar analysis. *Proc. Ore. Hort. Soc.* 63: 69-73.
59. Chaplin, M.H. 1973. Leaf analysis and fertilizer suggestions for apple and pear. *Proc. Ore. Hort. Soc.* 64: 47-50.
60. Chaplin, M.H., R.L. Stebbins, and M.N. Westwood. 1977. Effect of Fall-applied boron sprays on fruit set and yield of 'Italian' prune. *HortSci.* 12: 500-501.
61. Chaplin, M.H. and M.N. Westwood. 1980a. Effects of Pyrus species and related genera rootstocks on mineral uptake in 'Bartlett' pear. *J. Plant Nutrition* 2: 335-346.
62. Chaplin, M.H. and M.N. Westwood. 1980b. Nutritional status of 'Bartlett' pear on Cydonia and Pyrus species rootstocks. *J. Amer. Soc. Hort. Sci.* 105: 60-63.

63. Chaplin, M.H. and M.N. Westwood. 1980c. Relationship of nutritional factors to fruit set. J. Plant Nutrition 2: 477-505.
64. Chaplin, M.H., M.N. Westwood, and A.N. Roberts. 1972. Effects of rootstocks on leaf mineral content of 'Italian' prune (Prunus domestica L.). J. Amer. Soc. Hort.Sci. 97: 641-644.
65. Chatterjee, B.N., M. Chatterjee, and N.R. Das. 1980. Note on the difference in the response of wheat varieties to boron. Indian J. Agric. Sci. 50: 796.
66. Chaturiya, I.A. 1974. Effect of trace elements on the percentage of setting of citrus fruits. Subtrop. Kul't. (2): 48-50.
67. Chude, V. and G.O. Obigbesan. 1983. Safe and toxic application rates of boron for cocoa (Theobroma cacao) seedlings. Plant and Soil 74: 145-147.
68. Cohen, M.S. and L.S. Albert. 1974. Autoradiographic examination of meristems of intact boron-deficient squash roots treated with tritiated thymidine. Plant Physiol. 54: 766-768.
69. Coke, L. and W.J. Whittington. 1968. Interrelationships between boron and indol 3yl-acetic acid in the metabolism of bean radicles. J. Expt. Bot. 19: 295-308.
70. Copeland, E.B. and L. Kahlenberg. 1900. The influence of the presence of pure metals upon plants. Wisc. Acad. Sci. Arts, letters, Trans. (1899) 12: (454)-474.
71. Crane, J.C. 1975. The role of seed abortion and parthenocarpy in the production of blank pistachio nuts as affected by rootstocks. J. Amer. Soc. Hort. Sci. 100: 267-270.
72. Crassweller, R.M., D.C. Ferree, and E.J. Stang. 1981. Effects of overtree misting for bloom delay on pollination, fruit set, and nutrient element concentration of 'Golden Delicious' apple trees. J. Amer. Soc. Hort. Sci. 106: 53-56.
73. Dabas, A.S. and P.C. Jindal. 1981. The effect of boron and magnesium sprays on pollen viability and pollen germination in Thompson Seedless cultivar of grapes (Vitis vinifera). Agric. Sci. Dig. 1: 105-106.
74. Dani, H.M., G.S. Paul, V.K. Kakkar, H.S. Saini, and K. Sareen. 1970. Effect of boron on protein and nucleic acid content of wheat plant. Science 21: 425-430.

75. Dani, H.M., H.S. Saini, I.S. Allag, and K. Sareen. 1970. Role of boron in nucleic acid metabolism of germinating wheat seedlings. *Curr. Sci.* 39: 55-57.
76. Davison, R.M. 1971. Effect of early-season sprays of trace elements on fruit setting of apples. *N. Z. J. Agr. Res.* 14: 931-935.
77. Dearborn, C.H. and G.J. Raleigh. 1936. A preliminary note on the control of internal browning of cauliflower by the use of boron. *Proc. Amer. Soc. Hort. Sci.* 33: 622-623.
78. Delcheva, S. and Z. Makariev. 1982. (Studies on the causes of die-back in apple and pear trees in the Razlog region). *Gradinarska i Lozarska Nauka*, 19: 43-49.
79. Dixon, B., G.R. Sagar, and V.M. Shorrocks. 1973. Effect of calcium and boron on the incidence of tree and storage pit in apples of the cultivar Egremont Russet. *J. Hort. Sci.* 48: 403-411.
80. Dugger, W.M. 1983. Boron in plant metabolism. In: *Inorganic Plant Nutrition*. A. Lauchli and B.L. Bielecki (eds). *Encyclopedia of plant physiology, New series*. Vol. 15B: 626-650. Springer-Verlag, N.Y.
81. Dugger, W.M. Jr., T.E. Humphreys, and B. Calhoun. 1957. The influence of boron on starch phosphorylase and its significance in translocation of sugars in plants. *Plant Physiol.* 32: 364-370.
82. Dyar, J.J. and K.L. Webb. 1961. A relationship between boron and auxin in ¹⁴C translocation in bean plants. *Plant Physiol.* 36: 672-677.
83. Eaton, F. 1940. Interrelations in the effects of boron and indoleacetic acid on plant growth. *Bot. Gaz.* 101: 700-705.
84. Eaton, F.M. 1944. Deficiency, toxicity, and accumulation of boron in plants. *J. Agr. Res.* 69: 237-277.
85. Eaton, F.M. and G.Y. Blair. 1935. Accumulation of boron by reciprocally grafted plants. *Plant Physiol.* 10: 411-423.
86. Eaton, F.M., R.D. McCallum, and M.S. Mayhugh. 1941. Quality of irrigation water of the Hollister area of California with special reference to boron content and its effect on apricots and prunes. *U.S. Dept. Agr. Tech. Bull.* 746.
87. Epstein, E. 1973. Flow in the phloem and the immobility of calcium and boron: a new hypothesis in support of an old one.

- Experientia* (Basal) 29: 133-134.
88. Eschrich, W., H.B. Currier, S. Yamaguchi, and R.B. McNairn. 1965. Der Einfluss verstärkter callose building auf den stofftransport in Siebrohran. *Planta* 65: 49-64.
 89. Fallahi, E. and F.E. Larson. 1984. Rootstock influence on leaf and fruit mineral status of 'Bartlett' and 'd'Anjou' pear. *Sci. Hortic.* 23: 41-49.
 90. Fallahi, E., M.N. Westwood, M.H. Chaplin, and D.G. Richardson. 1984. Influence of apple rootstocks and K and N fertilizers on leaf mineral composition and yield in a high density orchard. *J. Plant Nutrition* 7: 1161-1177.
 91. Fallahi, E., M.N. Westwood, D.G. Richardson, and M.H. Chaplin. 1984. Effects of rootstocks and K and N fertilizers on seasonal apple fruit mineral composition in a high density orchard. *J. Plant Nutrition* 7: 1179-1201.
 92. Ferguson, W. and L.E. Wright. 1940. Microelement studies with special reference to the element boron. *Sci. Agr.* 20: 470-487.
 93. Ferwerda, J.D. 1954. Boron deficiency in oil palms in the Kasai Region of the Belgian Congo. *Nature, Lond.* 173: 1097.
 94. Flegmann, A.W. and R.A.T. George. 1977. Soils and other growth media. AVI Pub. Co. Inc., Connecticut. 177 pp.
 95. Gandhi, S.C. and B.V. Mehta. 1959. Studies on boron deficiency and toxicity symptoms in some common crops of Gujrat. *Indian J. Agric. Sci.* 29: 63-70.
 96. Ganguly, B. 1979. Note on seedlessness in some wheat varieties caused by boron deficiency. *Indian J. Agric. Sci.* 49: 384-386.
 97. Gauch, H.G. and W.M. Dugger, Jr. 1953. The role of boron in the translocation of sucrose. *Plant Physiol.* 28: 457-467.
 98. Gauch, H.C. and W.M. Dugger, Jr. 1954. The physiological action of boron in higher plants: a review and information. *Maryland Agr. Expt. Sta. Bull.* A-80: 1-43.
 99. Gauny, P. and F. Hugnet. 1964. Biochemical changes occurring in pear buds before and during flowering. *C.R. Acad. Agric. Fr.* 50: 391-399.
 100. Glenk, H. and W. Wagner. 1960. Untersuchung uber die borverteilung in einigen Oenotheren. *Ber. Deut. Botan. Ges.* 73: 463-470.

101. Gopal, N.H. 1975. Physiological studies on groundnut plants with boron toxicity. II. Effects on nitrogen metabolism. Turrialba 25: 144-147.
102. Grundwag, M. and A. Fahn. 1969. The relation of embryology to the low seed set in Pistacia vera (Anacardiaceae). Phytomorphology 19: 225-235.
103. Gupta, U.C. 1983. Boron deficiency and toxicity symptoms for several crops as related to tissue boron levels. J. Plant Nutrition 6: 387-395.
104. Gupta, U.C. and J.A. Cutcliffe. 1971. Determination of optimum levels of boron in rutabaga leaf tissue and soil. Soil Sci. 111: 382-385.
105. Gupta, U.C. and J.A. Cutcliffe. 1984. Effects of applied and residual boron on the nutrition of cabbage and field beans. Can. J. Soil Sci. 64: 571-577.
106. Guttridge, C.G. and J.M. Turnbull. 1975. Improving anther dehiscence and pollen germination in strawberry with boric acid and salts of divalent cations. Hort. Res. 14: 73-79.
107. Haas, A.R.C. 1930. Boron as an essential element for healthy growth of citrus. Bot. Gaz. 89: 410-413.
108. Haas, A.R.C. 1944. Boron in the palms and soils of date gardens in the Coachella valley of Southern California. Proc. Amer. Soc. Hort. Sci. 44: 34-42.
109. Haas, A.R.C. 1945. Boron content in almond, olive, and walnut trees. Proc. Amer. Soc. Hort. Sci. 46: 69-77.
110. Haas, A.R.C. and L.J. Klotz. 1931. Some anatomical and physiological changes in citrus produced by boron deficiency. Hilgardia, 5: 175-196.
111. Hacskeylo, J., R.F. Finn, and J.P. Vimmerstedt. 1969. Deficiency symptoms of some forest trees. Ohio Agri. Res. Develop. Cent., Res. Bull. No. 1015: 68 pp.
112. Haller, M.H. and L.P. Batjer. 1946. Storage quality of apples in relation to soil applications of boron. J. Agri. Res., Wash. D.C. 73: 243-253.
113. Hansen, C.J. 1945. The effect of boron on deciduous fruit trees. The Blue Anchor. Calif. Fruit Exch. 22(4): 12-15.
114. Hansen, C.J. 1958. Boron deficiency in prunes and plums in California. Proc. Ore. St. Hort. Soc. 50: 65-67.

115. Hanson, E.J. and P.J. Breen. 1985. Effects of fall boron sprays and environmental factors on fruit set and boron accumulation in 'Italian' prune flowers. J. Amer. Soc. Hort. Sci. 110: 389-392.
116. Heinicke, A.J., W. Reuther, and J.C. Cain. 1942. Influence of boron application on preharvest drop of McIntosh apples. Proc. Amer. Soc. Hort. Sci. 40: 31-34.
117. Hernandez, E. and N.F. Childers. 1956. Boron toxicity induced in a New Jersey peach orchard. Part II. Proc. Amer. Soc. Hort. Sci. 67: 121-129.
118. Hernando, V., P. Buenadicha, and M. Torres. 1975. Contents of free amino acids in sap from tomato plants treated with different levels of boron. Agrochimica, 19: 367-373.
119. Holevas, C.D. and D.A. Biris. 1980. Bitter pit-like symptoms in quinces; effect of calcium and boron sprays on the control of the disorder. In: Mineral Nutrition of Fruit Trees. D. Atkinson, J.E. Jackson, R.O. Sharples, and W.M. Waller (eds.), Butterworths, London.
120. Holley, K.T. and T.G. Dulin. 1939. Influence of boron on flower-bud development in cotton. J. Agri. Res., Wash. D.C. 59: 541-545.
121. Hu, Q.H. and M.G. Yang. 1982. (Preliminary studies on the symptoms of boron deficiency in Olea europaea). Plant Physiol. Comm. (Zhiwa Shenglixue Tongxun), No. 5: 14-17.
122. Hughes, M., M.H. Chaplin, and A.R. Dixon. 1979. Elemental composition of red raspberry leaves as a function of time of season and position on cane. HortSci. 14: 46-47.
123. Husa, J.G. and W.J. McIlrath. 1965. Absorption and accumulation of boron by sunflower plants. Bot. Gaz. 126: 186-194.
124. Igarashi, T. and T. Baba. 1975. Physiological disorder, so-called "Ironuke" and "Kubiore" in tulip plants. IV. Effect of the time of boron application on the occurrence of the physiological disorder and bulb yield. Nippon Dojo - Hiriyogaku Zasshi, 46: 483-490.
125. Ilyushchenko, V.P. and N.A. Ilyushchenko. 1981. (Effect of growth substances on the ability of meristematic cells to enter into DNA replication phase and RNA synthesis in boron-deficient pea roots). Vestnik Khar'kovskogo Universiteta, No. 211: 32-37.

126. Iqtidar, A. and S.F. Rehman. 1984. Effect of boron on the protein and amino acid composition of wheat grain. *J. Agric. Sci., Camb.* 103: 75-80.
127. Jaramillo, V. Juan. 1978. Symptoms of some mineral deficiencies in strawberries. *Rev. Inst. Colomb. Agropecu.* 13: 41-48.
128. John, M.K. and H.A. Daubeny. 1972. Influence of genotype, date of sampling, and age of plant on leaf chemical composition of red raspberry (*Rubus idaeus* L.). *J. Amer. Soc. Hort. Sci.* 97: 740-742.
129. Johnson, F., D.F. Allmendinger, V.L. Miller, and D. Polley. 1955. Fall application of boron sprays as a control for blossom blast and twig dieback of pears. *Phytopath.* 45: 110-114.
130. Johnston, E.S. and W.H. Dore. 1929. The influence of boron on the chemical composition and growth of the tomato. *Plant Physiol.* 4: 31-62.
131. Johri, B.M. and I.K. Vasil. 1961. Physiology of phloem. *Bot. Rev.* 27: 325-381.
132. Jolivette, J.P. and J.C. Walker. 1943. Effect of boron deficiency on the histology of garden beet and cabbage. *J. Agri. Res.* 66: 167-182.
133. Ju, H.Y., G. Chong, and B.B. Bible. 1982. Influence of boron nutrition on glucosinoletes and reducing sugars of turnip. *Can. J. Plant Sci.* 82: 1037-1042.
134. Kamali, A.R. and N.F. Childers. 1967. Effect of boron nutrition on peach anatomy. *Proc. Amer. Soc. Hort. Sci.* 90: 33-38.
135. Kamali, A.R. and N.F. Childers. 1970. Growth and fruiting of peach in sand culture as affected by boron and a fritted form of trace elements. *J. Amer. Soc. Hort. Sci.* 95: 562-656.
136. Kelley, J.R. 1980. An analysis of the effects of boron and plant growth regulators on flower development in filbert, *Corylus avellana* L. M.S. Thesis, Hort. Dept., OSU, Corvallis.
137. Kelley, W.P. and S.M. Brown. 1928. Boron in the soils and irrigation waters of Southern California and its relation to citrus and walnut culture. *Hilgardia*, 3: 445-458.
138. Kibalenko, A.P. and T.M. Sidorshina. 1971. Viability of

- pollen and seed formation in sugar beet as dependent on plant boron nutrition. Dapov. Akad. Nauk Ukr. RSR, Ser. B. 33: 558-562.
139. Kim, S.K., H.B. Lagerstedt, and L.S. Daley. 1985. Germination responses of filbert pollen to pH, temperature, glucose, fructose, and sucrose. HortSci. 20: 944-946.
 140. Kohl, H.C. Jr. and J.J. Oertli. 1961. Distribution of boron in leaves. Plant Physiol. 36: 420-424.
 141. Korban, S.S. and J.M. Swaider. 1984. Genetic and nutritional status in bitter pit-resistant and -susceptible apple seedlings. J. Amer. Soc. Hort. Soc. 109: 428-432.
 142. Kouchi, H. 1977. Rapid cessation of mitosis and elongation of root tip cells of Vicia faba as affected by boron deficiency. Soil Sci. Plant Nutrition, 23: 113-116.
 143. Kouchi, H. and K. Kumazawa. 1975. Anatomical responses of root tips to boron deficiency. I. Effect of boron deficiency on elongation of root tips and their morphological characteristics. Soil Sci. Plant Nutrition, 21: 21-28.
 144. Kovachich, W.G. 1952. Little leaf disease of oil palm (Elaeis guineensis) in the Belgian Congo. Trop. Agric. 29: 107-114.
 145. Kowalenko, C.G. and E.F. Maas. 1982. Some effects of fertilizer and lime application to filbert orchards in the Fraser valley of British Columbia. Can. J. Soil Sci. 62: 71-77.
 146. Kuijper, J. 1930. Boorzuur tagen de toziekte van de tabak. Deli Proefstation te Medan, Vlugschrift Nr. 50.
 147. Kwan, S.C., A.R. Hanson, and W.F. Campbell. 1969. The effects of different chemicals on pollen germination and tube growth in Allium cepa L. J. Amer. Soc. Hort. Sci. 94: 561-562.
 148. Lagerstedt, H.B. 1977. The occurrence of blanks in the filbert Corylus avellana L. and possible causes. Econ. Bot. 31: 153-159.
 149. Latimer, L.P. and G.P. Percival. 1943. How much borax can an apple tree tolerate?. Proc. Amer. Soc. Hort. Sci. 43: 21-24.
 150. Layne, R.E.C. and D.J. Hagedorn. 1964. Effect of boron and agar on germination of pea pollen in sucrose media. Crop Science 4: 39-42.

151. Lee, S. and S. Aronoff. 1967. Boron in plants: a biochemical role. *Science* 158: 798-799.
152. Leece, D.R. 1975. Diagnostic leaf analysis for stone fruits. IV. Plum. *Aust. J. Expt. Agri. and Anim. Husb.* 15: 112-117.
153. Linder, P.J., J.W. Brown and J.W. Mitchell. 1949. Movement of externally applied phenoxy compounds in bean plants in relation to conditions favoring carbohydrate translocation. *Bot. Gaz.* 110: 628-632.
154. Lohnis, M.P. 1937. Plant development in the absence of boron. *Meded. LandbHoogesch, Wageningen*, 41: 3-36.
155. Lohnis, M.P. 1940. Cited in: Stanley, R.G. and H.A. Linskens. 1974. *Pollen biology, biochemistry, management.* Springer-Verlag, New York. 307 pp.
156. Lombard, P.B. and M.N. Westwood. 1976. Performance of six pear cultivars on clonal Old Home, Double Rooted, and Seedling rootstocks. *J. Amer. Soc. Hort. Sci.* 101: 214-216.
157. Lovatt, C.J. 1985. Evolution of xylem resulted in a requirement for boron in the apical meristems of vascular plants. *New Phytol.* 99: 509-522.
158. Lovatt, C.J. and Bates, L.M. 1984. Early effects of excess boron on photosynthesis and growth of Cucurbita pepo. *J. Expt. Bot.* 35: 297-305.
159. Machado, M.A. and M.M. de S. Gomes. 1983. (Effect of boron deficiency on metabolism in tomato root tips). *Pesquisa Agropecuria Brasileira*, 18: 105-109.
160. MacLeod, D.J. and J.L. Howatt. 1935. The control of brown heart in turnips.(Abstract). *Sci. Agr.* 15: 435.
161. Mahmood, T. 1971. Boron toxicity causing tree collapse: Malady of citrus trees in the Izmir region of Turkey. *Plant Disease Reporter*, 55: 1132.
162. Marsh, R.P. 1942. Comparative study of the calcium-boron metabolism of representative dicots and monocots. *Soil Sci.* 43: 75-78.
163. Marsh, R.P. and J.W. Shive. 1941. Boron as a factor in the calcium metabolism of the corn plants. *Soil Sci.* 51: 141-151.
164. Martin, F.W. 1972. In vitro measurements of pollen tube

- growth inhibition. *Plant Physiol.* 49: 924-925.
165. Martin, L.W. 1975. Some effects of boron on small fruits. *Proc. Ore. Hort. Soc.* 66: 109-112.
166. Maze, P. 1915. Determination of the rare mineral elements necessary for the development of maize. *Compt. Rend.* 160: 211.
167. McIlrath, W.J. 1965. Mobility of boron in several dicotyledonous species. *Bot. Gaz.* 126: 27-30.
168. McLarty, H.R. 1936. Tree injections with boron and other materials as a control for drought spot and corky core of apple. *Sci. Agr.* 16: 625-633.
169. McLarty, H.R. and C.G. Woodbridge. 1950. Boron in relation to the culture of the peach. *Sci. Agr.* 30: 329-395.
170. Mcleod, K.A. 1975. The control of growth of tomato pollen. *Ann. Bot. (London).* 39: 591-596.
171. McNairn, R.B. and H.B. Currier. 1965. The influence of B on callose formation in primary leaves of Phaseolus vulgaris L. *Phyton* 22: 153-158.
172. Mengel, K. and E.A. Kirkby. 1982. Principles of plant nutrition. 3rd edition. International Potash Institute, Switzerland, 655 pp.
173. Miller, P.W. 1931. The brown stain disorder of filberts. *Proc. West. Nut Grs. Assoc.* 17: 165-170.
174. Misra, R.S. 1972. Effect of agar, boron, and growth regulators in germinating medium on pollen germination of java plum (Syzygium cumini). *Indian J. Agri. Sci.* 42: 16-20.
175. Mitchell, J.W. and J.W. Brown. 1946. Movement of 2,4-dichlorophenoxyacetic acid stimulus and its relation to the translocation of organic food materials in plants. *Bot. Gaz.* 107: 393-407.
176. Mitchell, J.W., W.M. Dugger, Jr., and H.G. Gauch. 1953. Increased translocation of plant-growth-modifying substances due to application of boron. *Science* 118: 354-355.
177. Montgomery, F.H. 1951. The effect of boron on the growth and seed production of Alsike clover, Trifolium hybridum L. *Can. J. Bot.* 29: 597-606.
178. Nakamura, M. 1903. Can boric acid in high dilution exert a stimulant action on plants? *Tokyo Imp. Univ., Col. Agr. Bul.*

- 5: 509-512.
179. Neales, T.F. 1960. Some aspects of boron on root growth. Aust. J. Biol. Sci. 13: 232-248.
 180. Neilsen, G.H., J.Yorston, W. Van Lierop, and P.B. Hoyt. 1985. Relationships between leaf and soil boron and boron toxicity of peaches in British Columbia. Can. J. Soil Sci. 65: 213-218.
 181. Neilson, B.V. and G.W. Eaton. 1983. Effects of boron nutrition upon strawberry yield components. HortSci. 18: 932-934.
 182. O'Brien, D.G. and R.W.G. Dennis. 1935. Raan or boron deficiency in swedes. Scottish J. Agri. 18: 326-333.
 183. Oertli, J.J. and W.F. Richardson. 1970. The mechanism of boron immobility in plants. Physiol. Plant. 23: 108-116.
 184. Okamoto, G. and A. Kabayashi. 1971. Effects of shoot pinching and boron sprays on the nutrient content and berry set of Muscat Alexandria II. J. Jap. Soc. Hort. Sci. 40: 212-224.
 185. O'Kelley, J.C. 1957. Boron effects on growth, oxygen uptake, and sugar absorption by germinating pollen. Amer. J. Bot. 44: 239-244.
 186. Ouyang, T., L. Qian, G.S. Gong and J.G. Zhou. 1984. (Problems concerning microelements in the citrus soils of Guilin). Soils (Turang), 16: 188-192.
 187. Painter, J.H. 1951. Filbert nutritional experiment. Proc. Ore. State Hort. Soc. 43: 179-182.
 188. Painter, J.H. 1953. Results of filbert nutritional studies in 1953. Proc. Nut Growers Soc. Ore. and Wash. 39: 183-186.
 189. Painter, J.H. 1956. Filbert containing no kernels. Proc. Nut Grs. Soc. Ore. and Wash. 42: 223-231.
 190. Painter, J.H. and H.E. Hammar. 1963. Effects of differential levels of applied K and B on 'Barcelona' filbert trees in Oregon. Proc. Amer. Soc. Hort. Sci. 82: 225-230.
 191. Perez, A., and N.F. Childers. 1982. Growth, yield, nutrient content and fruit quality of Carica papaya L. under controlled conditions. II. Boron effects. J. Agri. Univ. Puerto Rico. 66: 80-88.
 192. Perez-Lopez, A. and R.D. Reyes-Jurado. 1983. Effect of

- nitrogen and boron application on Carica papaya L. I. Growth and yield. J. Agri. Univ. Puerto Rico. 67: 181-187.
193. Perkins, H.J. and S. Aronoff. 1956. Identification of the blue-fluorescent compounds in boron-deficient plants. Arch. Biochem. Biophys. 64: 506.
194. Pfahler, P.L. 1967. In vitro germination and pollen tube growth of maize (Zea mays L.) pollen. I. Calcium and boron effects. Can. J. Bot. 45: 839-845.
195. Pfahler, P.L. 1968. In vitro germination and pollen tube growth of maize (Zea mays L.) pollen. II. Pollen source, calcium, and boron interactions. Can. J. Bot. 46: 235-240.
196. Pilbeam, D.J. and E.A. Kirkby. 1983. The physiological role of boron in plants. J. Plant Nutrition, 6: 563-582.
197. Pimienta, E. and V.S. Polito. 1982. Ovule abortion in 'Non Pareil' almond (Prunus dulcis (Mill) D.A. Webb. Amer. J. Bot. 69: 913-920.
198. Pollard, A.S., A.J. Parr, and B.C. Loughman. 1977. Boron in relation to membrane function in higher plants. J. Exptl. Bot. 28: 831-841.
199. Pope, D.T. and H.M. Munger. 1953. The inheritance of susceptibility to boron deficiency in celery. Proc. Amer. Soc. Hort. Sci. 61: 481-486.
200. Purvis, E.R. and R.W. Ruprecht. 1937. Cracked stem of celery caused by a boron deficiency in the soil. Florida Agr. Exp. Sta. Bull. 307: 1-16.
201. Rajaratnam, J.A. and J.B. Lowry. 1974. The role of boron in the oil-palm (Elaeis guineensis). Ann. Bot. 38: 193-200.
202. Rajaratnam, J.A., J.B. Lowry, P.N. Avadhani, and R.H.V. Corley. 1971. Boron: possible role in plant metabolism. Science 172: 1142-1143.
203. Ravindran, S. and Y.S. Chauhan. 1980. Studies in the reproductive biology of alkaloid-yielding Solanum. I. Temperature, sucrose and boron requirements for pollen germination and pollen tube elongation. J. Palynol. 16: 53-58.
204. Redington, C.B. and J.L. Peterson. 1983. Influence of boron on bud blasting and plant growth in Zinnia elegans. Bulletin of the Torrey Botanical Club 110: 77-79.
205. Reed, H.S. 1947. A physiological study of boron deficiency

- in plants. *Hilgardia* 17: 377-411.
206. Rohrbaugh, L.M. and E.L. Rice. 1949. Effect of application of sugar on the translocation of sodium 2,4-dichlorophenoxyacetate by bean plants in the dark. *Bot. Gaz.* 111: 85-89.
 207. Rowe, E.A. 1936. A study of heart-rot of young sugar beet plants grown in culture solutions. *Ann. Bot.* 50: 735-746.
 208. Roxas, M. 1911. The effect of some stimulants upon rice. *Philippine Agri. and Forester*, 1: (89)-97.
 209. Saini, H.S., H.M. Dani, I.S. Allag, and K. Sareen. 1969. Significance of boron in the metabolism of cotton plant. *Curr. Sci.* 38: 356-358.
 210. Schuman, G.E., A.M. Stanley, and D. Knudsen. 1973. Automated total nitrogen analysis of soil and plant samples. *Soil Sci. Soc. Amer. Proc.* 37: 480-481.
 211. Schuster, C.E. 1938. Response of fruit trees near "the Dallas", Oregon to applications of boron and zinc. *Proc. Amer. Soc. Hort. Sci.* 36: 99-101.
 212. Schuster, C.E. 1945. Progress report on the effects of boron on walnuts and of fertilizer applications to walnut and filbert trees. *Rpt. Western Nut Growers Assoc. (1945)*: 95-98
 213. Schuster, C.E. and R.E. Stephenson. 1947. Summary of thirteen years' work in soil and fertilizers in filbert and walnut orchards. *Proc. Nut Growers Soc. Ore. and Wash.* 33: 86-94.
 214. Scienza, A., R. Miravalle, M. Bobelli, and G. Dorotea. 1981. Effects of boron deficiency on the growth and chemical composition of Barbera berries. *Vignevini* 8: 37-42.
 215. Scott, E.G. 1960. Effect of supra-optimal boron levels on respiration and carbohydrate metabolism of Helianthus annuus. *Plant Physiol.* 35: 653-661.
 216. Scott, L.E. and A.L. Schrader. 1947. Effect of alternating conditions of boron nutrition upon growth and boron content of grape vines in sand culture. *Plant Physiol.* 22: 526-536.
 217. Shear, C.B. and M. Faust. 1971. Nutritional factors influencing the mineral contents of apple leaves. *J. Amer. Soc. Hort. Sci.* 96: 234-240.
 218. Shiralipour, A., H.C. Harris, and S.H. West. 1969. Boron deficiency, amino acid and protein contents of peanut leaves.

Crop Sci. 9: 455-456.

219. Shkol'nik, M.J., T.A. Krupnikora, and N.N. Dmitrieva. 1964. Influence of boron deficiency on some aspects of auxin metabolism in the sunflower and corn. *Sov. Plant. Physiol.* 11: 164-169.
220. Shkol'nik, M.Ya., T.A. Krupnikova, and Yu.S. Smirnov. 1981. Polyphenol oxidase activity and sensitivity to boron deficiency in some monocotyledonous and dicotyledonous plants. *Fiziol. Rast. (Moscow)*. 28: 391-397.
221. Sommer, A.L. and C.B. Lipman. 1926. Evidence of the indispensable nature of zinc and boron for higher green plants. *Plant Physiol.* 1: 231-249.
222. Spiers, J.M. 1982. Seasonal variation of leaf nutrient composition in 'Tifblue' rabbiteye blueberry. *J. Amer. Soc. Hort. Sci.* 107: 255-257.
223. Spurr, A.R. 1957. The effect of boron on cell-wall structure in celery. *Amer. J. Bot.* 44: 637-650.
224. Stanley, R.G. and E.A. Lichtenberg. 1963. The effect of various boron compounds on in vitro germination of pollen. *Physiol. Plant.* 16: 337-346.
225. Stanley, R.G. and H.F. Linskens. 1974. *Pollen: biology, biochemistry, and management.* Springer-Verlag, N.Y. 307 pp.
226. Stebbins, R.L. 1973. Use of leaf analysis for walnuts and filberts. *Proc. Nut Growers Soc. Ore. and Wash.* 58: 37-42.
227. Stebbins, R.L. 1977. New information on foliar feeding of tree fruits and nuts. *Proc. Ore. Hort. Soc.* 68: 92-94.
- 227a. Stebbins, R.L. 1984. What is known about brown stain? *Proc. Nut Growers Soc. Ore., Wash, & B.C.* 69: 101-108.
228. Stoyanov, D. 1972. Changes in amino acid composition of lucerne as influenced by boron nutrition. *Soil and Fertilizer*, 35: 35-39.
229. Szabo, S.A. 1981a. Examination of the boron content of plant substances as well as certain factors affecting the uptake and distribution of boron II. *Bot. Kozl.* 68: 195-204.
230. Szabo, S.A. 1981b. Examination of the boron content of plant substances as well as certain factors affecting the uptake and distribution of boron III. *Bot. Kozl.* 68: 273-283.

231. Thomas, W.H. 1952. Boron contents of floral parts and the effect of boron on pollen germination and tube growth of Lilium species. M.S. Thesis, Univ. Maryland, MD.
232. Thompson, A.H. and L.P. Batjer. 1950. The effect of boron in the germinating medium on pollen germination and pollen tube growth for several deciduous tree fruits. Proc. Amer. Soc. Hort. Sci. 56: 227-229.
- 232a. Thompson, M.M. 1967. Role of pollination in nut development. Pro. Nut Growers Soc. Ore. & Wash. 53: 31-36.
233. Thompson, M.M. 1979. Growth and development of the pistillate flower and nut in 'Barcelona' filbert. J. Amer. Soc. Hort. Sci. 104: 427-432.
234. Uribe-Henao, A. and N. Salazar-Arias. 1981. (Effect of minor elements on coffee yields). Cenicafe 32: 122-142.
235. Van de Venter, H.A. and H.B. Currier. 1977. The effect of boron deficiency on callose formation and ¹⁴C translocation in bean (Phaseolus vulgaris L) and cotton (Gossypium hirsutum L.). Amer. J. Bot. 64: 861-865.
236. Van Goor, B.J. and P. Van Lune. 1980. Redistribution of potassium, boron, iron, magnesium, and calcium in apple trees determined by an indirect method. Physiol. Plant. 48: 21-26.
237. Vasil, I.K. 1964. Effect of boron on pollen germination and pollen tube growth. p. 107-119. In: Pollen physiology and fertilization. H.F. Linskens (ed.). North-Holland, Amsterdam.
238. Vaughan, A.K.F. 1977. The relation between the concentration of boron in the reproductive and vegetative organs of maize plants and their development. Rhod. J. Agric. Res. 15: 163-170.
239. Visser, T. 1956. Proc. Kon. Nederl. Akad. Wetensch. Ser. C, 59: 685. Cited in: Stanley, R.G. and H.F. Linskens (eds.). Pollen biology, biochemistry, and management. Springer-Verlag, New York. 307 pp.
240. Vogel, Guenter. 1973. Effect of high doses of Mn, Cu, Zn, and B on some legumes. Angew. Bot. 47: 159-182.
241. Wadleigh, C.H. and J.W. Shive. 1939. A microchemical study of the effects of boron deficiency in cotton seedlings. Soil Sci. 47: 33-36.
242. Walker, J.C. 1944. Histology - pathologic effect of boron deficiency. Soil Sci. 57: 51-54.

243. Wall, J.R. and C.F. Andrus. 1962. The inheritance and physiology of boron response in the tomato. Amer. J. Bot. 49: 758-762.
244. Wang, D.N. and W. H. Ko. 1975. Relation between deformed fruit disease of papaya and boron deficiency. Phytopathology 65: 445-447.
245. Warington, K. 1923. The effect of boric acid and borax on the broad bean and certain other plants. Ann. Bot. 37: 629-672.
246. Warington, K. 1926. The changes induced in the anatomical structure of Vicia faba by the absence of boron from the nutrient solution. Ann. Bot. 40: 27-42.
247. Watanabe, R., W. Chorney, J. Skok, and S.H. Wender. 1964. Effect of boron deficiency on polyphenol production in the sunflower. Phytochemistry 3: 391-393.
248. Watanabe, R., W.J. McIlrath, J. Skok, W. Chorney, and S.H. Wender. 1961. Accumulation of scopoletin glucoside in boron-deficient tobacco leaves. Arch. Biochem. Biophys. 94: 241-243.
249. Weaver, R.J. and H.R. DeRose. 1946. Absorption and translocation of 2,4-dichlorophenoxyacetic acid. Bot. Gaz. 107: 509-521.
250. Webber, I.E. 1935. Histological characteristics of plants grown in toxic concentrations of boron. J. Agri. Res. 50: 189-194.
251. Westwood, M.N. 1978. Mahaleb x Mazzard hybrid cherry stocks. Fruit varieties Journal, 32: 39.
252. Westwood, M.N. and H.O. Bjornstad. 1980. Mineral nutrient content of leaves of several apple (Malus) species. Compact Fruit Tree 13: 67-71.
253. Westwood, M.N. and G. Stevens. 1979. Factors influencing cherry and prune set. Proc. Oregon State Hort. Soc. 70: 175-179.
254. Whittington, W.J. 1957. The role of boron in plant growth. I. The effect on general growth, seed production and cytological behavior. J. Expt. Bot. 8: 353-367.
255. Whittington, W.J. 1959. The role of boron in plant growth. II. The effect on growth of the radicle. J. Expt. Bot. 10: 93-103.

256. Wilcox, L.V. 1960. Boron injury to plants. USDA Agri. Inform. Bull. No. 211.
257. Wittstein, A. and F. Apoiger. 1857. Ann. der Chemie Und Pharmacie (Liebig), 103: 362-364. Cited by R.W.G. Dennis. The relation of boron to plant growth. Science Progress 32: 58-69. (1937).
258. Woodbridge, C.G. 1973. Effects of rootstocks and interstocks on nutrient levels in 'Bartlett' pear leaves, on tree growth, and on fruit. J. Amer. Soc. Hort. Sci. 98: 200-202.
259. Woodbridge, C.G., A. Carney, and H.R. McLarty. 1952. A boron deficiency in pear growing in soil having an adequate boron content. Sci. Agri. 32: 440-442.
260. Woodbridge, C.G. and P.C. Crandall. 1967. The boron contents of 'Bartlett' buds and flower clusters. Proc. Wash. State Hort. Assoc. 63: 187-191.
261. Woodbridge, C.G., A. Venegas, and P.C. Crandall. 1971. Boron content of developing pear, apple, cherry flower buds. J. Amer. Soc. Hort. Sci. 26: 613-615.
262. Worley, R.E. 1977. Pecan leaf analysis: I. Varietal, fertilizer, and seasonal effects. Commun. Soil Sci. Plant Anal. 8: 533-549.
263. Yogaratnam, N. and D.W.P. Greenham. 1982. The application of foliar sprays containing nitrogen, magnesium, zinc, and boron to apple trees. I. Effects on fruit set and cropping. J. Hort. Sci. 57: 151-158.
264. Yogaratnam, N. and D.S. Johnson. 1982. The application of foliar sprays containing nitrogen, magnesium, zinc, and boron to apple trees. II. Effects on the mineral composition and quality of the fruit. J. Hort. Sci. 57: 159-164.
265. Yokomizo, H. 1977. Boron nutrition of Japanese pear trees. I. Development of abnormal symptoms caused by the lack of boron supply in solution cultures. Kaju Shikenjo Hokoku, A. 4: 93-103.
266. Zittle, C.A. 1951. Reaction of borate with substances of biological interest. Adv. Enzymol. 12: 493-527.

APPENDICES

Summary of Appendices

The growth of nuts increased much more rapidly than the growth of leaves (Appendix Figure I). At earlier dates, dry weight of leaves was higher than it was in nuts, but later in the season the nut weight was much greater than the leaf weight. The percent dry weight of leaves remained always higher than that in nut tissues, while percent dry weight of nuts decreased until the 4th week of June, after which date it again increased. The decrease was due to rapid growth in nut size which, probably, was associated with accumulation of water more than the dry matter content.

Appendix I indicated an overall view for fruit set characters of 4 hazelnut orchards in 1984. The variation in all these characters between orchards was significant. Compared to controls B sprays also affected these parameters. However, between 2 levels of B concentration, the effect was not significant. The size of nut clusters (number of nuts in a cluster) was influenced by time of spray applications. The variation in fruit set parameters between different orchards was shown in Appendix III. The percentage of 1-nut clusters was the highest in Orchard # 1 which had the lowest percentage of 4 or more nut clusters. Orchard # 1 produced the lowest number of clusters and fewer nuts.

In 1985, although there was orchard-to-orchard variation, B treatments affected some parameters of fruit set (Appendix II). Boron spray decreased 1-nut clusters but, in general, it increased

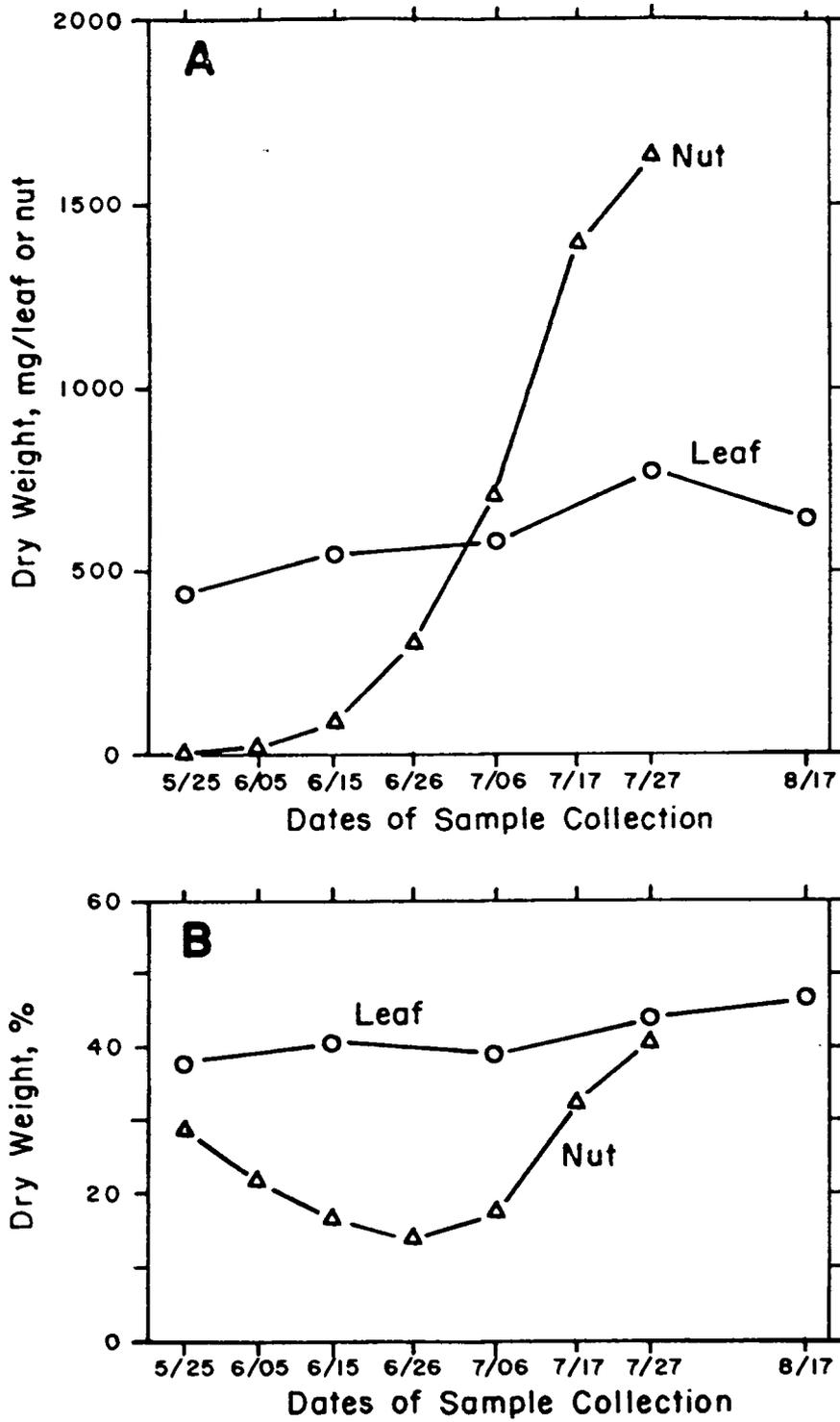
2 or more nut clusters. Compared to controls, following B sprays, the number of clusters and of nuts increased significantly in 3 of 5 orchards. In 1985, the number of nuts per cluster was higher (2.1 to 2.8 nuts/cluster) than it was in 1984 (1.7 to 1.9 nuts/cluster). Fall-applied B sprays not only increased fruit set in all orchards (Appendix V) but also the sprays doubled the B content in dormant bud, catkin, and female flower bud (Appendices VI and VII).

Rootstocks used for 'Barcelona' hazelnut trees did not affect nut production of the scion. When B was applied there was a significant interaction between B and rootstock (Appendix VIII). In unsprayed controls, 'Barcelona' grafted on 'Daviana' had fewer nuts than when on its own roots. Following B sprays, Barcelona/Daviana combination produced the highest number of nuts.

Mineral composition of leaves (Appendix X) and of nuts (Appendix XI) changed through the season. In both tissues, N, P, K, S, Cu, and Zn decreased as the growing season progressed. The level of Ca, Mn, Fe, and B increased in leaves and decreased in nut tissues. When 'Barcelona' was grafted on 'Daviana' P, S, Ca, and Mg contents were increased and K and Fe levels were decreased in leaves while N, P, Ca, Fe, Cu, and Zn levels increased in nut tissues (Appendix XIII). Following B application (Appendix XII) the amount of some mineral elements at certain dates was significantly increased in leaves (P, K, S, and Fe) and in nuts (N, P, S, and Ca).

The quality of hazelnut kernels and nuts was influenced by

the crop load (Appendix XIV). The orchard which produced 63% cluster set had significantly smaller nuts and smaller kernels than those in the 43% set orchard. Kernels were shrivelled and did not blanch as well as in the low set orchard. Early in the season, all minerals and dry matter were partitioned more in leaves, while late in the season most mineral elements and dry weight were partitioned in nut tissues (Appendix XV). Dry weight and mineral content in the stem tissue were very little as compared to other tissues of a fruiting twig both early and late in the season.



Appendix 1 (fig.). Seasonal changes in dry matter content in leaves and nuts of 'Barcelona' hazelnut trees, 1985: A. Dry weight, g. B. Percent dry weight.

Appendix I. ANOVA (mean squares) for 11 fruit set parameters of 'Barcelona' hazelnuts, 1984.

S.V.	D.F.	B.D.	C.D.	1-nut	2-nut	3-nut	4 & > nut	clusters	set, %	nuts	nuts/cls.	BD/CD
orchards (O)	3	1211**	269**	1131.0**	592**	280**	202**	79865**	3649**	328501**	0.467**	21.67**
R/O	20											
treatments (T)	12	76	15	267.5**	46**	74**	11**	3392**	137	23751**	0.100	0.64
cont. vs spr.(CS)	1	13	27*	564.0**	88**	155**	24**	25196**	1079**	132770**	0.300**	3.78**
boron (B)	1	111	9	0.3	4	11	1	1	1	16	0.002	0.02
dates (D)	5	38	14	483.4**	61**	133**	19**	2461	76	27406**	0.180**	0.60
B x D	5	119	15	45.8	31	13	3	641	37	3040	0.007	0.18
orch. x treat.	36	78	8	33.3	16	8	4	851	46	2935	0.014	0.54
CS x O	3	27	1	30.0	6	17	7	695	38	1203	0.003	0.43
B x O	3	11	6	12.7	10	15	7	942	52	2417	0.002	0.37
D x O	15	97	7	27.0	12	7	6	880	42	3188	0.013	0.53
B x D x O	15	83	12	44.3	22	6	2	835	50	3132	0.020	0.60
error	240	73	9	36.3	17	11	4	1344	113	5949	0.016	0.36

* and ** are significance levels at 5% and 1%, respectively. BD means blossom density (number of flower clusters on a limb/cross-sectional area of the limb). CD is cluster density (number of clusters per cross-sectional area of the limb).

Appendix II. ANOVA (mean squares) for 8 fruit set characters of 'Barcelona' hazelnut orchards, 1985.

S.V.	D.F.	1-nut	2-nut	3-nut	4 & nut	total clusters	set,%	total nuts	total nuts/cl.
Orch.# 1 treat.	1	311**	129.6*	14	12.0	8911*	442**	82723**	0.072*
error	30	15	19.2	11	7.6	1349	37	8503	0.010
Orch.# 2 treat.	1	156*	29.3	31	148.5**	17550**	726**	227566**	0.320**
error	22	23	18.3	16	11.6	781	20	6478	0.022
Orch.# 3 treat.	1	144**	126.0	10	15.7	17523**	781**	119197**	0.033
error	18	17	30.0	29	20.6	1300	42	9025	0.031
Orch.# 4 treat.	1	11	5.0	3	0.1	12881	454*	104150	0.001
error	22	5	20.3	4	12.2	3197	93	28592	0.016
Orch.# 5 treat	1	174**	0.1	41	49.3	616	10	22647	0.111
error	18	22	33.1	19	32.0	1493	48	19839	0.063

* and ** are significance levels at 5% and 1%, respectively.

Appendix III. Orchard to orchard variation in mean (of control & spray treatments) values for 11 fruit set characters in 4 orchards of 'Barcelona' hazelnuts, 1984.

Fruit set characters	Orch. # 1 (TT)	Orch. # 2 (CY)	Orch. # 3 (LT)	Orch. # 4 (BH)	LSD _{.05}	LSD _{.01}
blossom density (BD)	25.2	22.3	17.9	27.0	2.7	3.5
crop density (CD)	7.4	9.7	5.9	9.8	0.9	1.2
cluster set, %	29.8	45.9	34.1	38.0	3.3	4.4
1-nut clusters, %	47.9	40.6	45.4	40.0	1.9	2.5
2-nut clusters, %	39.4	43.1	36.5	40.7	1.3	1.7
3-nut clusters, %	10.1	13.1	12.3	14.6	1.0	1.3
4 & more-nut clusters, %	2.6	3.2	6.1	4.9	0.6	0.8
total flower clusters	505.0	496.0	521.0	507.0	20.7	27.2
total nut clusters	153.2	230.8	179.4	193.6	11.5	15.1
total number of nuts	252.5	406.7	323.1	358.5	24.2	31.7
number of nuts/cluster	1.7	1.8	1.8	1.9	0.1	0.1
blossom/cluster = BD/CD	3.6	2.3	3.1	2.8	0.2	0.3

Please refer Appendix I for definition of BD and CD.

Growers' names: Twedt (TT), Chambers (CY), Lemert (LT), and Bush (BH).

Appendix IV. Mean values for 7 fruit set characters in 5 'Barcelona' hazelnut orchards, 1985.

Fruit set characters	Orch. # 1 (RR)		Orch. # 2 (OSU)		Orch. # 3 (TT)		Orch. # 4 (CY)		Orch. # 5 (CO)	
	control	boron	control	boron	control	boron	control	boron	control	boron
1-nut cls.	25.8	19.6**	22.1	17.0*	22.4	17.1**	11.1	9.7	21.3	15.4*
2-nut cls.	44.6	48.6*	43.4	41.2	43.1	48.1	42.2	43.2	42.0	41.8
3-nut cls.	18.3	19.6	21.1	23.3	23.2	21.7	24.9	25.6	23.8	26.6
4 & more cls.	11.0	12.2	13.3	18.3**	11.3	13.1	21.6	21.5	12.9	16.1
flower cls.	522.0	530.0	536.0	526.0	532.0	518.0	525.0	525.0	534.0	543.0
nut cls.	276.2	309.6*	232.7	286.8**	199.9	259.1**	331.6	377.9	270.4	281.5
total nuts	601.3	702.9**	556.4	751.2**	460.1	614.5**	927.2	1058.9	664.8	732.1
nuts/cls.	2.1	2.3*	2.4	2.6**	2.3	2.4	2.8	2.8	2.4	2.6

* and ** are significant at 5% and 1% levels, respectively.

Orchards: RR = Rogers, OSU = Oregon State Univ., TT = Twedt, CY = Chamb., and CO = Chamb. old.

Note: Boron sprays reduced 1-nut clusters; however, it increased 2-nut clusters (Orch. # 1) and 4- or more nut clusters (Orchard # 2).

Appendix V. Effect of B sprays applied in October, 1983 on fruit set in 'Barcelona' hazelnut trees in 4 orchards during 1984.

Orchards	Control	300 ppm B	600 ppm B	Mean
# 1	22.5p	27.5p	27.2p	25.7a
# 2	33.0r	39.5qr	41.2qr	37.9bc
# 3	30.0pq	35.3pq	34.0pq	33.1b
# 4	36.5r	47.2r	45.7r	43.1c
Mean	30.5a	37.3b	37.0b	

a,b,&c Overall mean separation by Duncan's Multiple Range Test at 1% level.

p,q,&r Mean separation within each column by Duncan's Multiple Range Test at 5% level.

Appendix VI. Boron content of dormant bud, catkin, and female flower bud of 'Barcelona' hazelnut as influenced by two concentrations of B sprays applied in the fall^x.

Tissues	Control	300 ppm B	600 ppm B	LSD at 1%
Dormant bud ^y	32	45	62	9
Catkin ^y	35	52	68	14
Female flower bud ^z	28	35	43	3

^xBoron was sprayed on 20 October, 1983. Tissues were collected on ^y1 November, 1983, and on ^z26 February, 1984.

Appendix VII. Effect of B sprays applied in October, 1983 on B levels in female flower buds collected from 4 hazelnut orchards on 26 February, 1984.

Orchards	control	300 ppm B	600 ppm B	mean
# 1	27.8a pq	35.5b pq	42.2c p	35.2pq
# 2	26.2a p	33.7b p	41.8c p	33.9p
# 3	26.4a p	33.6b p	43.2c pq	34.4p
# 4	30.1a q	37.8b q	45.6c q	37.9q
Mean	27.6a	35.1b	43.2c	

a,b,&c Mean separation within each row by Duncan's Multiple Range Test at 1% level.

p,&q Mean separation within each column by Duncan's Multiple Range Test at 5% level.

Appendix VIII. Effect of 600 ppm B sprays on number of nuts in 'Barcelona' trees as affected by 2 different rootstocks of hazelnut in 1985.

Scion/stock	control	+ boron	F-test:	
Barcelona/self (flower cls. #)	598.3 (554.8)	727.8 (527.5)	boron (B)	**
Barcelona/Daviana (flower cls. #)	514.5 (517.3)	774.5 (523.5)	rootstock (RS)	NS
			B x RS interaction	*

Statistical significance at 1% (**), at 5% (*), and none (NS).

Appendix IX. Stepwise multiple regression equation for fruit set (FS) in 'Barcelona' hazelnut with the 2 (of 11 tested) mineral elements that accounted for the most variability at different leaf and nut sampling dates in 1985.

Tissues	Equation	r^2
Leaf: 5/25	FS = 0.67 Mn + 0.41 B + 32.89	0.72
6/15	FS = 0.73 Mn + 0.35 B + 34.51	0.69
7/06	FS = 0.72 Mn + 0.39 B + 31.23	0.66
7/27	FS = 0.67 Mn + 0.37 B + 31.50	0.66
8/17	FS = 0.63 Mn + 0.44 B + 32.54	0.68
Nut: 5/25	FS = -0.66 Cu + 0.35 K + 36.14	0.55
6/07	FS = -0.74 Cu + 0.25 Fe + 75.38	0.53
6/15	FS = -0.81 Cu + 0.29 B + 58.56	0.55
6/26	FS = -0.99 Cu + 0.32 Zn + 72.87	0.65
7/06	FS = -0.68 Cu + 0.24 S + 60.57	0.57
7/17	FS = +0.55 Mn + 0.24 S + 30.98	0.46
7/27	FS = -0.81 Mn + 0.37 P + 77.61	0.47

Appendix X. Seasonal changes in mineral content of 'Barcelona' hazelnut leaves at different dates of sampling during 1985.

Collection dates	Mineral elements ^x										
	N	P	K	S	Ca	Mg	Mn	Fe	Cu	B	Zn
25 May	2.49	0.20	0.97	0.17	1.03	0.27	136.0	110.7	7.1	44.4	24.5
15 June	2.28	0.17	0.86	0.14	1.06	0.26	138.0	163.1	5.8	49.4	19.7
06 July	2.46	0.17	0.88	0.14	1.23	0.28	168.5	188.7	5.7	57.3	19.1
27 July	2.16	0.18	0.66	0.13	1.32	0.27	155.5	168.3	4.1	63.3	15.5
17 August	1.91	0.15	0.54	0.12	1.44	0.26	164.2	281.1	4.1	60.0	14.6
LSD at 1%	0.11	0.01	0.07	0.01	0.06	0.01	16.3	27.9	0.5	10.7	2.3

^xAll macronutrients are expressed on percent and micronutrients are in ppm dry weight basis.

Each value is the mean of 3 replications in each of 4 orchards.

Appendix XI. Seasonal changes in the nut mineral content of 'Barcelona' hazelnuts at different dates of sampling during 1985.

Collection dates	Mineral elements ^x										
	N	P	K	S	Ca	Mg	Mn	Fe	Cu	B	Zn
25 May	3.19	0.46	1.27	0.26	0.83	0.37	68.7	122.7	15.1	23.2	53.2
05 June	2.86	0.43	1.39	0.22	0.62	0.29	49.4	92.5	14.4	21.0	43.5
15 June	2.27	0.26	1.04	0.14	0.34	0.18	28.6	65.7	11.2	17.2	23.1
26 June	1.70	0.20	0.84	0.12	0.29	0.13	29.3	64.2	10.7	16.5	17.4
06 July	1.33	0.15	0.72	0.10	0.22	0.11	25.8	52.9	9.2	15.2	13.2
17 July	0.84	0.09	0.39	0.07	0.12	0.06	15.6	30.5	7.2	8.7	8.2
27 July	0.78	0.08	0.29	0.05	0.12	0.05	18.0	35.8	6.1	7.8	7.4
LSD at 1%	0.10	0.02	0.05	0.01	0.03	0.01	4.4	6.9	0.9	2.8	1.8

^xMacroelements are expressed on percent and microelements are in ppm dry weight basis. Each value is the mean of 3 replications in each of 4 orchards.

Appendix XII. Changes in mineral element content in hazelnut nut and leaf tissues in response to boron sprays, 1985.

Tissue	Date	Treat	N	P	K	S	Ca	Fe
Nut	5/25	C	3.20	0.460	1.27	0.262	0.832	122.8
		B	3.18	0.473**	1.30	0.268*	0.894**	129.6
	6/05	C	2.86	0.428	1.39	0.219	0.623	92.5
		B	2.89	0.443**	1.40	0.229**	0.643*	93.3
	6/26	C	1.69	0.198	0.84	0.120	0.290	64.2
		B	1.76*	0.210**	0.87	0.135**	0.303	68.2
	7/27	C	0.78	0.08	0.29	0.054	0.119	35.8
		B	0.85	0.08	0.32	0.058	0.123	31.4
Leaf	5/25	C	2.48	0.201	0.970	0.168	1.031	110.7
		B	2.51	0.209	0.968	0.177**	1.035	105.5
	6/15	C	2.27	0.167	0.862	0.137	1.062	163.1
		B	2.35	0.183**	0.913*	0.146**	1.085	162.1
	8/17	C	1.91	0.148	0.543	0.123	1.439	281.1
		B	1.95	0.152	0.596**	0.129*	1.395	341.5**

Control (C), boron applied (B). Level of Mg, Mn, Cu, and Zn in leaf and in nut was unchanged by B sprays.

* & ** are significance at 0.05 and 0.01 level, respectively.

Appendix XIII. Effect of rootstocks on leaf and nut mineral content in 'Barcelona' hazelnut trees in 1985.

Scion tissues -----	Mineral elements ^z								
	N	P	K	S	Ca	Mg	Fe	Cu	Zn
leaf: -----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Barc/self	2.25	0.20	0.79	0.11	1.06	0.26	134	6	19
Barc/Daviana	2.26	0.23	0.69	0.12	1.37	0.25	104	6	20
F-test ^y	NS	**	**	*	**	*	**	NS	NS
nut:									
Barc/self	1.81	0.24	0.87	0.13	0.35	0.18	59	11	24
Barc/Daviana	1.88	0.26	0.88	0.13	0.41	0.17	63	13	26
F-test ^y	**	**	NS	NS	**	NS	**	**	**

^ySignificance levels at 5% (*), 1% (**), and none (NS).

^zNitrogen, P, K, S, Ca, and Mg are expressed on percent of dry weight and Fe, Cu, and Zn are in ppm.

Rootstock did not affect Mn, and B levels in leaf and nut tissues.

Appendix XIV. Quality of 'Barcelona' hazelnuts in 2 orchards which had variable crop load in 1985.

Crop load	Size of nuts and kernels g/nut	g/kernel	Kernel weight,%	Blanks (%)
43% set	3.6	1.6	44.2	12.3
63% set	2.8**	1.2**	41.3**	13.2

Differences were significant at 1% (**) level.

Note: The orchard which had 63% set had shrivelled kernels and did not blanch well as in the other. Several kernels were split upon cracking when the set was 43%.

Appendix XV. Partitioning of dry matter (DM) and mineral elements in fruiting twigs of hazelnut².

Tissue	DM	N	P	K	S	Ca	Mg	Mn	Fe	Cu	B	Zn
Leaf:												
% on June	78	79	68	77	80	82	79	90	77	64	89	62
% on Aug.	17	23	15	23	24	54	33	58	36	14	51	30
% net gain	- 2	-16	- 3	4	- 1	26	- 4	38	18	- 1	24	3
Stem:												
% on June	9	7	8	10	6	9	6	3	11	15	5	20
% on Aug.	3	3	3	5	2	8	2	3	5	5	3	11
% net gain	- 2	0	1	3	1	7	0	4	3	2	1	3
Nut:												
% on June	7	8	14	7	6	3	6	2	5	10	2	10
% on Aug.	66	60	64	33	44	24	49	23	39	70	23	48
% net gain	84	97	82	43	60	43	84	35	54	87	38	82
Husk:												
% on June	6	6	9	6	7	6	9	5	7	10	4	8
% on Aug.	14	14	18	38	30	15	15	16	20	12	23	11
% net gain	16	19	21	50	40	24	20	23	25	12	37	12
Total net gain (%)	318	144	305	277	230	100	128	165	230	358	131	143

²Figures are averages of untreated and B-treated tissues.

Appendix XVI. Relationship (r values) between blossom density (BD) and crop (cluster) density (CD), between CD and fruit set (FS), and between BD and FS in 4 orchards during 1984.

Orchards	BD vs. CD	CD vs. FS	BD vs. FS
Twedt	0.96**	0.33	0.19
Chambers	0.89**	0.49	0.11
Lemert	0.88**	0.75**	0.49
Bush	0.81**	0.22	-0.31

Note: There was a high correlation between blossom density and cluster density in all 4 orchards. Because of higher r values CD may be more related to fruit set than BD. This indicates that the crop density may be useful parameter for fruit set counts in hazelnut.