Main and Interactive Effects of Boron on Lowbush Blueberry (*Vaccinium angustifolium* Ait.) Nutrition, Growth, Development, and Yield

By

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DEDICATION

To my parents, David and Frances Perrin, your love and kindness has provided me with many opportunities. I appreciate the advice and direction that you have given me. Your selflessness and support has helped steer me in the right direction and instilled confidence. Your strength has been a true inspiration and I will be forever indebted. Thanks for the devotion and encouragement.

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ABSTRACT

The use of foliar-applied boron as a nutrient source in lowbush blueberry production was evaluated in three studies in Atlantic Canada in the vegetative and cropping phases of production in 1997 and 1998, respectively. Foliar-applied B was absorbed by the blueberry plant more quickly than soil-applied B. Though leaf B levels were not increased to the sufficiency range (30 $\mu g \cdot g^{-1}$) in the crop year, it was a safer method of application. Soil-applied B at 2 $kg \cdot ha^{-1}$ caused an increase in leaf B levels of 456% and a subsequent yield decrease of 19% compared with non-treated plots. Foliar applications were absorbed much more quickly, more consistently and with little environmental impact.

Studies investigating the optimum timing and frequency of foliar B applications indicated that leaf B levels were significantly increased following applications at bloom (BC) and at fruit set (FC) when tissue was sampled after fruit set. Foliar applications made at tip dieback-sprout year (SY) and bloom-crop year (BC), though non-significant, increased yield (15.6%) compared with the control at two sites combined. The SY+BC application significantly increased yields compared with treatments only at tip dieback (SY), only prior to bloom (BC), and at tip dieback, bloom and prior to fruit set (SY+BC+FC). There was no increase in the average berry weight, thus yield increases were attributed to increased number of berries per stem. The optimum timing and frequency of application of foliar-applied B was determined to be at tip dieback-sprout year and bloom of the crop year.

The third study evaluated the interactive effects of foliar-applied B with Ca, and Mg. When applied only in the sprout year, there was no significant effect of B, Ca, or Mg on yield. Applications during both the sprout and crop years resulted in significant effects of Mg and B. Yield was maximized when B was applied at a high level and Mg at a low level or Mg at a high level and B at a low level. Berry weight responded very similarly to yield over the same range of factors. Examination of the yield components indicated increased inflorescences and flowers per inflorescences were attributed to B and Ca. Winter injury to the vascular tissue was decreased by the application of Ca, while B had a negative effect on the winter survival of the terminal buds. These studies provide an insight into the effect of foliar B sprays as a cultural practice to maximize lowbush blueberry yield.

LIST OF ABBREVIATIONS AND SYMBOLS

Q_{10}	Quotient representing a change in respiration over a 10 °C interval.
ATPase	Adenosinetriphosphatase.
IAA	Indole acetic acid.
RNA	Ribonucleic acid.
P.E.I.	Prince Edward Island.
N.S.	Nova Scotia.
ppm	Parts per million (equivalent to 1 g of active ingredient per 1000L of water).
SY	Tip dieback growth stage in the sprout year.
BC	Bloom growth stage in the crop year.
FC	Fruit set growth stage in the crop year.
$Na_2B_40_7$	Granular sodium borate fertilizer.
NSWBI	Nova Scotia Wild Blueberry Institute.
ICAP	Inductively coupled plasma spectroscopy.
rpm	Revolutions per minute.
Proc GLM	General linear models procedure in SAS.
ANOVA	Analysis of variance.
LSMeans	Least squared means test in SAS.
RSM	Response surface methodology.
Proc RS Reg	Response surface regression procedure in SAS.

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CHAPTER 1 - General Introduction and Literature Review.

1.1. Introduction

The lowbush blueberry is a woody, perennial plant species native to northeastern North America which has evolved to become the most important horticultural crop in Nova Scotia. Blueberries grow in acidic soils and field development involves the removal of competing vegetation from wooded areas and old pastures (Eaton, 1994). Commercial blueberries are commonly managed in a two-year production cycle. During the first year (i.e., sprout year) the plants grow vegetatively and set fruit buds. Flowering occurs in the second year followed by pollination, fruit set, and harvest. The fields are then pruned by burning or mowing in the autumn of the cropping year or in the spring of the sprout year to maximize yields and harvest efficiency (Eaton, 1994). In 1997, 22.0 million lbs worth $13.5 million were harvested in Nova Scotia; the industry is worth approximately $33.7 million to the Nova Scotia economy (McIsaac, 1997).

The use of the macronutrients nitrogen (N), phosphorus (P), and potassium (K) has been examined in lowbush blueberry production (Smagula and Hepler, 1978; Eaton and Patriquin, 1988). Information on micronutrients in lowbush blueberry production is lacking, though they are important in plants for their roles in the synthesis of chlorophyll, constituents of enzymes and plant growth regulators and substrates for biochemical reactions (Mengel and Kirkby, 1987). Because blueberries are grown on acidic soils, soil-applied fertilizers are less likely to be efficient sources of nutrients (Chen *et al.*, 1998). This is due to a reduction in availability as a result of binding to iron (Fe) and aluminum (Al) hydroxides. Boron (B)

availability is further decreased by high mobility in the soil which increases losses due to leaching (Jin *et al.*, 1988). The soils in most blueberry fields are considered marginal for other agricultural uses (Eaton, 1994; Sanderson *et al.*, 1996). Because of these confinements, it is felt that foliar applications of micronutrients will be beneficial and will supplement the nutrient requirements of the lowbush blueberry. Preliminary work has shown that foliar-applied B produces fruit that is higher in sugar and anthocyanins and firmer berries than untreated controls (Percival, 1997).

Boron is one of seven essential micronutrients required for plant growth and development (Gupta, 1979). The physiological role of B is probably the least understood of any micronutrient (Gupta, 1979). Boron has a very narrow range between deficiency and toxicity, thus it is a difficult nutrient to manage in commercial production (Marschner, 1997).

1.2. Boron Availability in the Soil

Typically, the lowbush blueberry grows in poor soils which subsequently, poses challenges in managing the B status of the soil and the plant. Boron is commonly found in the soil as boric acid (H_3BO_3) or as the borate anion (BO_3^{-3}). Boron is most available to plants at lower pH, as the borate ion is less adsorptive to the soil particles (Mengel and Kirkby, 1987). Therefore, increasing the pH of soils through the process of liming reduces the plant available B (Mengel and Kirkby, 1987). Soil type also influences B availability with increased clay and oxy hydroxide content reducing the leaching of B by providing a greater number of adsorptive sites (Jin *et al.*, 1988). Therefore, as pH decreases, increased clay and hydroxide content can reduce B leaching. However, in lowbush blueberry

production, B availability can be hindered where Al availability is high (Gupta *et al.*, 1985). This is supported by a study that concluded binding of B by Al resulted in B deficiency and thus impairing ascorbate metabolism (Lewkaszewski and Blevins, 1996). Others report that there is no significant effect of pH on B availability (Neilsen *et al.*, 1985).

Boron replenishment in soil is hindered because of its high mobility in the soil resulting in the removal of B from the soil through the leaching process (Jin *et al.*, 1988). This is most common in situations where there may be excessive rainfall (Gupta, 1979) or in sandy soils with low organic matter (Gupta and Arsenault, 1986). A lack of soil moisture, which causes reduced mass flow and reduced diffusion, restricts B assimilation (Gupta, 1979). Dry soil conditions limit B movement in the plant, because movement occurs predominantly in the transpiration stream of most plant species (Gupta, 1979). However, B movement can also occur via the phloem (Brown and Hu, 1994; Shelp *et al.*, 1995). Levels in the soil can be misleading if taken soon after B is applied or if there is a build-up of B deep in the soil profile (Neilsen *et al.*, 1985).

1.3. Plant Assimilation of Boron

Boron is assimilated by plants as undissociated boric acid (Gupta, 1979). There is uncertainty whether B uptake is an active or passive process (Mengel and Kirkby, 1987). The general consensus is that the active component of B uptake is small and that assimilation follows water through the roots. Gupta (1979) reported that it can be passively distributed through the transpiration system and that metabolic activity is not responsible for B assimilation and allocation. Brown and Hu (1994) concluded similar findings in squash,

sunflower and tobacco. In this study no multiphasic kinetics were detected, metabolic inhibitors did not suppress uptake, and within the temperature range tested the Q_{10} was less than two, indicating passive absorption.

1.4. Boron Remobilization and Translocation

Boron is relatively immobile within plants (Brown and Hu, 1994) and translocation appears to be facilitated through the xylem by way of transpiration. This is supported by B accumulation found at leaf tips and root margins (Mengel and Kirkby, 1987). Movement of B predominantly through the xylem via the transpirational stream explains why B deficiency generally begins at growing points (Gupta, 1991). Once allocated to a tissue via transpiration, recent studies have indicated that B remains immobile due to its forming a non-exchangeable complex within the cell wall (Brown and Hu, 1994).

In apples, the uptake of B appeared limited but was well distributed in the apple fruit indicating phloem mobility (Chamel and Andreani, 1985). Brown and Hu (1996) using isotope tracing found that B is phloem mobile in *Prunus*, *Pyrus*, and *Malus* species. This movement of B was a result of the phloem mobility of boron-sorbitol complexes (Brown and Hu, 1996). Boron mobility was greater in young leaves of bearing olives during anthesis than non-bearing trees which had received foliar applications. This enabled the B requirements of flowers and developing fruits to be met (Delgado *et al.*, 1994). Boron has been shown to cause callose formation in sieve tubes of the phloem; thus translocating through the xylem may be a plant adaptation (Mengel and Kirkby, 1987).

Evidence of B mobility has been reported in various plant species including cotton,

grapes, and turnips (Shelp *et al.*, 1995). Shelp (1988) determined that B was phloem mobile by examining phloem exudate in broccoli. In peaches, foliar-applied B was translocated to the fine roots. The highest B concentrations were found in the upper leaves suggesting that xylem transport is the main pathway for B movement (Shu *et al.*, 1994b). Another study with peaches by Shu *et al.* (1994a) showed B was also phloem mobile. Difficulties in quantifying assimilation and movement in peaches include: (1) the amount of uptake by peaches is so small that it is rapidly diluted by growth, and (2) the translocation occurs very rapidly making it difficult to measure.

Peach trees are capable of translocating B with the primary sink being the fruit (Shu *et al.*, 1994a). In the tomato, Oertli (1993) found that removing plants from sources of excess B to a B free solution resulted in translocation of B from the growing points to the roots. Root B concentration increased significantly when B was translocated to this sink (Oertli, 1993). The concentration of B in xylem sap was decreased when B was not supplied after being present at adequate levels; phloem concentration remained unchanged (Shelp, 1988). It was also noted that the concentration gradient decreased from mature tissues to young, developing sinks resulting in B retranslocation from source leaves to these sinks (Shelp, 1988).

1.5. Physiological Role of Boron in Plants

Recent advancements in plant nutrition have provided insight to the physiological importance of B in a number of crucial plant functions. Boron is important in root and meristematic tissue extension, translocation of sugars, the pyrimidine biosynthetic pathway,

cell wall and membrane structure, and synthesis of phytohormones (Mengel and Kirkby, 1987).

Boron forms poly hydroxy compounds with the wall components increasing cell wall stability (Mengel and Kirkby, 1987; Bolanos *et al.*, 1996). Cell wall structure has been found to be important in regulating B uptake in barley (Jenkin *et al.*, 1993). When B is present in adequate amounts, the cell wall is a fine structure that is both strong and flexible. Because B deficiency is detrimental to cellulose biosynthesis (Pilbeam and Kirkby, 1983), cell wall thickening occurs. This results in abnormal formation of the Golgi apparatus (Marschner, 1997) and fewer lamellae are noted after boron is removed (Mengel and Kirkby, 1987).

Boron acts as a transducer in membranes through the sequestering of sulfhydrol groups. A strong, positively charged complex in cell membranes is formed (Tanada, 1995) that regulates the flow of ions through membrane pores. In particular, B affects the membrane permeability to K ions (Pilbeam and Kirkby, 1983) and improves integrity of the membranes (Cakmak *et al.*, 1995). Within the membrane, lower ATPase activity has been observed in B deficient tissue which directly influences the movement of monocovalent cations into cells (Pilbeam and Kirkby, 1983). These alterations in membrane characteristics have been associated with a reduction in membrane polarization (Schon *et al.*, 1990) and have been related to the cause of such B deficiency symptoms as effects on sugar translocation and auxin movement (Schon *et al.*, 1990).

Pollen germination and pollen tube growth are both affected by B deficiency (Jenkin *et al.*, 1993). The stigma and style require high B levels for physiological inactivation of callose, otherwise, a callose-borate complex is formed at the pollen-tube style interface. As

a result, B is more critical in reproductive organs, seed and grain formation than in vegetative growth (Marschner, 1997). The length of the wheat pollen-tube increased with increasing B (Cheng and Rerkasem, 1993) and grain set was increased by increasing B supply in the medium (Rerkasem *et al.*, 1993a). Grain set failure was associated with poorly developed pollen and anthers (Cheng and Rerkasem, 1993; Rerkasem *et al.*, 1993a).

Disturbances in phytohormone production (Pilbeam and Kirkby, 1983) and yield of strawberry (May and Pritts, 1993) have been associated with B deficiencies. Cell division decreases related to B deficiency are attributed to its role B in the metabolism, transport or action of auxin type hormones (Gupta, 1979). These deficiencies have also been linked with depressed biosynthesis of cytokinins (Pilbeam and Kirkby, 1983). Therefore, lack of cell division may be a combination of low cytokinin levels and high auxin levels. This can subsequently explain the yield increases when B is applied.

Boron forms enzyme inhibition complexes that regulate phenol synthesis. These phenolic compounds prevent the formation of toxic quinones and oxygen free radicals (Cakmak *et al.*, 1995) and regulate indole acetic acid (IAA) oxidase activity. Increased IAA oxidase activity subsequently increases auxin levels. High auxin concentration effects included radial rather than longitudinal cell expansion, root tip browning, and increased formation of lateral roots (Marschner, 1997). Boron also modulates 6-phosphogluconate dehydrogenase by complexing with its substrate. When B is in adequate supply, the glycolysis pathway is favored rather than the pentose phosphate pathway which produces phenolic compounds (Mengel and Kirkby, 1987).

Inhibited growth in B deficient plants has also been attributed to decreased nucleic

acid concentration (Marschner, 1997). Plants in low B situations exhibit: 1) damage at apical meristems, 2) affected nucleic acid levels, 3) rapid cessation of root growth, 4) low levels of phosphorus incorporated in the ribonucleic acid (RNA) and 5) inhibited uracil synthesis resulting in the inhibition of sucrose biosynthesis, which may be mistaken as poor sucrose translocation. Research conducted by Gauch and Dugger (1953) with peas and lima beans exhibited greater sugar translocation in plants with adequate B levels. They suggested that B forms a sugar-borate complex that moves more easily and readily through cell membranes than non-borated, non-ionized sugar molecules. When B was in adequate supply, improved translocation of sugar to growing points was observed. Therefore, Gauch and Dugger (1953) concluded B deficiency symptoms are expressions of sugar deficiency in plant parts.

Most B deficiency diseases are related to B mobility (Shelp *et al.*, 1995) and include brown heart of rutabaga, cracked stem of celery, heart rot of beets, brown-heart of cauliflower and internal brown-spot of sweet potatoes (Gupta, 1979). Boron deficiency has resulted in protein decomposition or deceleration of protein synthesis causing increased amino acid levels in sunflowers (Marschner, 1997). Under saturated carbon dioxide levels and high light intensity, photosynthesis is limited in sunflowers by B levels (Kastori *et al.*, 1995). The diminished photosynthesic rate is attributed to increased accumulation of photoassimilates in the leaves (Kastori *et al.*, 1995).

1.6. Interactions of Boron and Other Nutrients

A difficulty in finding optimum levels of nutrients to maximize crop yield lies in the fact that nutrients interact with each other (May and Pritts, 1993). Treatment of soybeans

with either foliar-applied B and magnesium (Mg) resulted in no increase in seed yield. However, a combined treatment of B+Mg resulted in increased yield when neither was deficient in the soil (Reinbott and Blevins, 1995). They also found that the benefits of soil-applied B were greater prior to planting, rather than at planting. In apples, foliar-applied B with urea and magnesium sulfate resulted in damaged leaf tissue (Yogaratnam and Greenham, 1982).

Split-foliar applications of calcium (Ca) with B increased fruit set and subsequently yield in two cranberry cultivars, although 100 fruit weights were somewhat lower but not significant (De Moranville and Deubert, 1987). Calcium levels tend to be low in cranberries due to leaching in the sandy, acidic soils. Boron improved the movement of Ca from leaves to fruit. Therefore, the increase in yield may be a result of increased Ca, B or both (De Moranville and Deubert, 1987). The positive effect of B and Ca was negated when a manganese (Mn) / zinc (Zn) treatment was also applied (De Moranville and Deubert, 1987). Interveinal chlorosis and necrosis of the growing point in cauliflower occurred when B was deficient and Mn was high, leaf B levels decreased thus suppressing B related physiological activities (Chatterjee *et al.*, 1989).

Soil-applied B and Ca had no effect on potato tuber yields. Calcium tissue levels were not increased though leaf B levels were (Gupta and Sanderson, 1993). In tomatoes, B deficiency became more pronounced as Ca concentration was increased while B toxicity symptoms were less pronounced as Ca was increased (Yamauchi *et al.*, 1985). Increase of Ca in the lower leaves was attributed to increased translocation from the roots to the lower leaves and lack of retranslocation from the lower leaves to immature leaves (Yamauchi *et*

al., 1985). Calcium treatments increased the negative effect of B in soybeans (Schon and Blevins, 1987). *Pinus radiata* cell cultures showed that Ca and B activated an acceptor molecule when they were bound at acceptor sites; Mg competes with Ca to bind at the site and inactivates the molecule (Teasdale and Richards, 1990). This suggests that there may be an active component of B uptake. Therefore, the influence on B binding sites could influence its uptake (Weinbaum *et al.*, 1994). The addition of Mg at high (near toxic) boron levels in peas had a positive effect on yield (Salinas *et al.*, 1986).

In alfalfa, nitrogen fertilization of B deficient soil resulted in rapid expression of deficiency symptoms (Willett *et al.*, 1985). Possible explanations include i) the additional nitrogen resulted in accelerated growth causing B deficiency at the growing points, or ii) a physiological interaction affected B uptake by the roots or transfer from the roots to shoots. Boron added to pistachio seedlings increased concentration of leaf sugars and root starch while decreasing root glucose concentration (Picchioni and Miyamoto, 1991b). Boron deficiency appeared in pecans as interveinal chlorosis followed by necrosis in interveinal areas (Picchioni and Miyamoto, 1991a).

Boron added in soil to *Pinus radiata* resulted in increased plant B levels and improved N, P, and K uptake. Boron deficiency resulted in leader die-back of *Pinus radiata*. Trees that were given B fertilizer exhibited an increase in height and apical dominance (Hopmans and Clerehan, 1991).

1.7. Effect of Boron on Fruit Set

Increasing fruit set is one method that lowbush blueberry growers can use to improve the yield potential of the crop. Since adequate supplies of B are necessary in young, developing fruits for maximum fruit set, the use of foliar applications directly to developing fruits may be most efficient in meeting this requirement (Shrestha *et al.*, 1987). Fruit set of prune trees was not affected by foliar applications of B in a warm spring when fruit set was high (Hanson and Breen, 1985). However, in a cool spring when fruit set was low, treated trees had higher fruit set than the control. The mechanism by which this occurred was not understood because pollen-tube growth was not enhanced and pistil length was marginally decreased (Hanson and Breen, 1985). Hanson (1991) noted that autumn B sprays increased its levels in apple, pear, plum and sour cherry and suggested that during autumn applications, B moved from leaves into flower buds and was present in flowers the following spring.

Boron deficiencies have led to a decrease in seed yield of soybean, peanut and black gram (*Vigna mungo* L.)(Rerkasem *et al.*, 1993b). Stem infusions of B increased soybean yield by increasing pods on the lateral branches (Schon and Blevins, 1987). In a follow-up study Schon and Blevins (1989) reported increased branches and numbers of pods per branch when soybeans were treated with split foliar applications of B at the field level. The same results did not occur when B was soil-applied. In highbush blueberry, foliar B applications increased berry number per plant by 12% over control plants and reduced tip dieback due to winter injury by up to 75% in some cultivars (Blevins *et al.*, 1996).

The effectiveness of B in crop plants is dependent upon the genotype and environment to which it is applied. Because of the heterogenous nature of lowbush blueberry

fields, variable results may occur (Chen *et al.*, 1998). Variations in response to foliar-applied B have been noted among cultivars of hazelnuts (Ferran *et al.*, 1997). Boron did not affect the number of nuts per clusters (Ferran *et al.*, 1997) as expected based on results in soybeans (Schon and Blevins, 1989) and strawberry (May and Pritts, 1993). Shrestha *et al.* (1987) found that foliar-applied B raised leaf levels and induced increased fruit set in sprayed trees. Results from this study showed fruit set was increased in trees that were considered to have deficient, optimal and excessive tissue concentrations when B was supplied, suggesting guidelines for B nutrition need further investigation. Rerkasem *et al.* (1993b) found similar variations in response to B among soybean genotypes.

1.8. Boron and Fruit Quality

Presently, blueberry producers are concerned with growing a product that is both appealing to consumers of fresh berries and is easily processed. Large, firm berries , which contain high levels of anthocyanins and sugars, have low titratable acidity and a longer shelf life are favored. Adequate B levels in other horticultural crops have improved fruit quality. Boron deficiency in strawberries is a cause of malformed fruit. Strawberries treated with B showed increased levels of B through the summer but by the following spring there was no difference in B levels between treated plants and controls (Riggs and Martin, 1988). This suggests that applications of B in blueberries may be required in both sprout and crop years to maintain adequate plant B levels. Yield of strawberry at pH 6.5 improved with increased soil-applied B at high phosphorus levels but decreased at low soil phosphorus levels. At pH 5.5, yield significantly improved with increased B due to higher fruit count per inflorescence

and fruit size. However, there were no interactions with P and Zn noted (May and Pritts, 1993). Although foliar-applied B in apples enhanced the coloration, a higher incidence of cracking also occurred (Yogaratnam and Johnson, 1982).

There was no effect of B on fruit sugar content in highbush blueberries (Blevins *et al.*, 1996). However, foliar-applications of B in lowbush blueberries in the sprout year resulted in improved fruit quality of the subsequent crop (Percival, 1997). Two combined sites had greater soluble solids, anthocyanins and fruit firmness and lower titratable acidity (Percival, 1997).

1.9. Boron Toxicity

As previously mentioned, B has a narrow window of sufficiency in plants. In many crops B toxicity has been shown to be as detrimental to crops as its deficiency. Excess B in the soil solution decreased garlic bulb weight and diameter; but did not affect the percentage of solids (Francois, 1991). Francois (1991) also reported that excess B decreased the percentage of solids in onions but did not increase weight or diameter. Boron toxicity in the presence of Zn deficiency in sour oranges can be alleviated by the addition of Zn (Swietlik, 1995). Areas of chlorosis progressed to necrosis in pecans under toxic levels of B (Picchioni and Miyamoto, 1991a). Celery plants harvested from toxic B levels were bitter, immature and not of marketable quality (Francois, 1988). Toxic B levels decreased the average weight and caused necrosis of the wrapper leaves of lettuce (Francois, 1988). Excess B caused increased fruit numbers of tomatoes, but reduced the size and grade of the fruit (Francois, 1984).

1.10. Summary

The lowbush blueberry, a member of the *Ericaceae* family, is probably not able to retranslocate B from tissue to developing sinks through the phloem as well as other fruits (e.g., members of the *Rosaceae* family) (Brown and Hu, 1996). The constraints in managing B levels in the poor, acidic soils in which blueberries grow, coupled with the lack of mobility of B present a challenge to growers. Foliar applications are a logical way to better meet the B nutritional requirements of plants (May and Pritts, 1993). In fruit trees (apple, pear, prune and sweet cherry) foliar-applied B uptake was 88-96% complete within 24 hours (Picchioni *et al.*, 1995). This suggests that foliar-application of B is a method of supplying developing tissues, quickly and efficiently. It is necessary to determine whether foliar-applied B is both assimilated and allocated to developing tissue more efficiently than granular applications.

It is necessary to determine the growth stages at which foliar applications must be made, in order to deliver B to sinks through the transpiration stream. It is felt that split applications of foliar-applied B will be necessary at fruit bud development, 80% bloom and at fruit set to minimize winter injury and maximize yields. However, this is complicated by the fact that nutrient interactions occur and is a consideration when trying to optimize applications. It is necessary to understand the impact of foliar-applied B on the status of other nutrients, especially Ca and Mg. Calcium has increased yield in cranberries when applied with B (De Moranville and Deubert, 1987), while B and Mg applications have increased yield in soybeans (Schon and Blevins, 1989). Calcium and Mg compete for binding sites when they are soil-applied. An understanding of how foliar-applied B, Ca and Mg affect vegetative growth and yield components is required.

CHAPTER 2 - Efficiency of Soil vs. Foliar-Applications of Boron and Determination of Optimum Time and Frequency of Boron Applications.

ABSTRACT

Two studies were conducted to examine the effect of foliar-applied boron (B) usage on the assimilation and allocation of B in the lowbush blueberry plant and to determine the optimum timing of application of B in the production cycle. The first trial compared the rate of assimilation of foliar-applied B with soil-applied B to determine which is most effective in quickly supplying the plant with increased boron levels. A two-factor (foliar-applied B at 0 and 300 ppm, soil-applied B at 0 and 2 $kg \cdot ha^{-1}$) factorial experiment was arranged in a randomized block design located at Debert, N.S. Tissue and soil samples taken repeatedly through the growing season indicated that the soil-applied B treatment increased soil B levels by the third day after application and leaf tissue B levels seven days after application. At the conclusion of the study, leaf B levels in treatments receiving the soil-applied B were 456% greater than the control. Such high concentrations led to B toxicity and a decrease in yield with soil-applied B treatments yielding 19% less than untreated plots. Though the main effect of the foliar-applied B treatment did not have a significant effect on leaf boron levels, they were increased by 21% compared with the control within 24 hours after application and for the remainder of the study. Therefore, foliar applications of B are a more effective method of rapidly increasing the concentration of B in leaf tissue than soil-applied B. This study was inconclusive in determining whether B was transported via phloem or xylem.

Further investigation of the mode of assimilation and allocation is necessary.

The second study examined the optimum combination of application times of foliar-applied B on tissue B levels, vegetative growth and reproductive components. A 2^3 factorial design was arranged in commercial fields at Wood Islands, P.E.I., and at Benvie Hill, N.S. Foliar B applications of 300 ppm B (Bortrac150) were applied in 310 $L \cdot ha^{-1}$ of water at terminal dieback of the sprout year (SY), at bloom of the crop year (BC), and fruit set of the crop year (FC). Applications at bloom and fruit set of the crop year were most effective in increasing leaf B levels. Application during the sprout year did not increase B levels in either the leaf tissue or the buds. The treatment consisting of B applications at SY and BC produced 15.6% greater than the control. Reproductive components and vegetative growth measured at bloom and after fruit set were not affected by the SY application but were affected by the BC and FC treatments. A mild winter and spring may have negated the potential impact of the SY treatments. The results of this study suggest that applications in both the crop and sprout year are necessary to maximize yield.

2.1. Introduction

Boron is commonly the most deficient of all the micronutrients in crop production (Gupta, 1979), on a national and international basis (Gupta *et al.*, 1985). These deficiencies occur because B is very mobile in the soil and is easily leached (Gupta *et al.*, 1985). Leaching is intensified in poor (i.e., stony, weakly structured, or low organic matter) soils and also those with low clay contents, which are common traits of blueberry fields (Sanderson *et al.*, 1996). A survey of blueberry fields in Maine found that 39 of 75 fields were B deficient (Smagula, 1993). Although a formal survey has not recently been conducted, trends are similar in the Maritimes (Percival, personal communication). The minimum leaf tissue standard established for B in lowbush blueberry tissue is 24 ppm in the sprout year and 30 ppm in the crop year indicate deficiency (Trevett, 1972).

Boron, if utilized in commercial fields, is usually applied in a granular borate (i.e., $Na_2B_4O_7$) form during the sprout year. However, there are constraints to the use of granular B products. High application rates are necessary in the spring to maintain adequate leaf B concentration throughout the growing season (Neilsen *et* al., 1985). There is a lag effect observed between application and assimilation by the plant as the granules must be dissolved and uptake is driven predominantly by the transpiration stream (Brown and Hu, 1994). Once B is allocated to a tissue, it forms a non-exchangeable complex with the cell wall and becomes immobile (Brown and Hu, 1994). Recent research suggests that phloem mobility of B may be greater in some species than previously believed (Hu and Brown, 1996).

The lag in assimilation and lack of redistribution may not be a concern in maintaining B levels for vegetative growth, however, B plays an important role in reproductive processes.

Pollen germination and pollen tube growth are both affected by B deficiency (Jenkin *et al.*, 1993). The stigma and style require high levels for physiological inactivation of callose. Otherwise, a callose-borate complex is formed at the pollen tube-style interface limiting the elongation of the pollen tube. As a result, B is more critical in reproductive organs and seed and grain formation than in vegetative growth (Marschner, 1997). The length of the wheat pollen-tube increased with higher B concentration (Cheng and Rerkasem,1993); grain set was also increased by elevating the B supply in the medium (Rerkasem *et al.*, 1993a). Grain set failure was associated with poorly developed pollen and anthers (Cheng and Rerkasem, 1993; Rerkasem *et al.*, 1993a). Seed production in alfalfa was increased by 600% while vegetative growth was increased only 3% with supplemental B (Piland *et al.*, 1944). Recent studies have shown that B improved fruit yield in other *Vaccinium* species such as cranberries (DeMoranville and Deubert, 1987) and highbush blueberries (Blevins *et al.*, 1996). These benefits have been noted when plants were not only deficient but also when leaf tissue levels were sufficient and toxic (Hanson, 1991). This indicates that providing floral organs with B supplements can improve fruit set regardless of the B status.

Foliar applications have been shown to be a quick and efficient mode of supplying B to developing tissues (Hanson and Breen, 1985). The process of flowering in the lowbush blueberry is a short-lived process, the blossom remains in tact for a period of only 7-10 days (Wood, 1962). Wood (1962) observed that by the seventh day pistil receptivity declined and fruit set was between 15 and 58% in the five clones investigated. Foliar B applications will ensure that the B supply is adequate during this critical period whereas the pollination window may be missed if relying on soil-applied B. This evidence suggests that foliar sprays

are more efficient than granular applications in meeting the B requirement necessary at critical growth stages.

To incorporate foliar B applications as a management practice, the optimum time of application must be known. Blevins *et al.* (1996) found that foliar-sprays were most beneficial to highbush blueberries when applied prior to leaf drop and after bud break. Therefore, understanding the developmental physiology of the blueberry is of the utmost importance.

Flower bud development is initiated during the non-cropping year at tip die-back or terminal cessation (Aalders and Hall, 1964). The buds must withstand severe (< -20 °C) and fluctuating temperatures (i.e., freeze-thaw-freeze) characteristics of cold stress. Survival of buds is greatest when there is a sufficient blanket of snow for protection. Boron is essential in the cell wall structure. It forms poly hydroxy compounds with the wall components increasing cell wall stability (Mengel and Kirkby, 1987; Bolanos *et al.*, 1996). When B is present in adequate amounts, the cell wall is a fine structure that is both strong and flexible (Pilbeam and Kirkby, 1983).

Autumn B sprays have shown increased levels in apple, pear, plum, and sour cherry (Hanson, 1991). Subsequently, B moved from the leaves into flower buds and was present in flowers the following spring (Hanson, 1991). Reduced winter injury has been noted due to B foliar sprays in the highbush blueberry. In one season tip dieback was reduced by 75% in some cultivars (Blevins *et al.*, 1996) making a strong case for autumn applications.

Enhanced fruit set via improved fertilization is one method lowbush blueberry growers can use to increase the yield potential of the crop. Boron was especially effective

in increasing the fruit set of prune trees in years where environmental factors reduced the overall set (Hanson and Breen, 1985). A consideration which must be made prior to applications at bloom is the effect on both native and introduced pollinators. Boric acid has been used as an insecticide to control ants and cockroaches (Kaakeh and Bennett, 1997). Boron applications at this time are important, as deficiencies have led to a decrease in seed yield of soybean, peanut, and black gram (*Vigna mungo* L.)(Rerkasem *et al.*, 1993b).

After fertilization, berry development occurs in three distinct stages. Stage I is marked by a rapid increase in the pericarp (Finn and Luby, 1986). During stage II, pericarpal development is retarded while the endosperm develops rapidly (Finn and Luby, 1986). Stage III is a second phase of rapid development of the pericarp (Finn and Luby, 1986). Adequate B supply is necessary in young, developing fruits for maximum fruit set and retention (Shrestha *et al.*, 1987). Applying foliar B sprays directly to developing fruits may be the best method to quickly and effectively meet the requirement (Shrestha *et al.*, 1987).

The effects of B on fruit quality are somewhat contradictory. There was no effect of B on fruit sugar content in highbush blueberries (Blevins *et al.*, 1996). However, foliar-applications of B in lowbush blueberries in the sprout year resulted in improved fruit quality of the subsequent crop during an extremely dry cropping year (Percival, 1997). The results of two combined sites had greater soluble solids, anthocyanins, and fruit firmness, and lower titratable acidity (Percival, 1997). Boron has been implicated in improving sugar translocation (Gauch and Dugger, 1953), thus it is likely to affect sugar levels in berries. It is also involved in the synthesis of phenols (Mengel and Kirkby, 1987) which influence the antioxidant capacity of the berry. However, this area requires further research.

Two studies were conducted to evaluate the consequences of foliar B applications as a management practice in lowbush blueberry production. The first study investigated the assimilation and allocation dynamics of soil-applied B compared with foliar-applied B. The influence of the two methods of application on leaf and soil levels were investigated as well as the subsequent effects on yield and berry weight. The objective of the second study was to determine at which of the three stages of development (floral initiation, flowering, fruit set) or combination of the stages, foliar B applications were most beneficial via examination of tissue B levels, vegetative growth, and reproductive components.

2.2 Materials and Methods

2.2.1 Efficiency of Soil vs. Foliar-Applications of Boron.

The plant material used in this experiment was indigenous mixtures of *V. angustifolium* clones in a commercially managed field at the Nova Scotia Wild Blueberry Institute, Debert, N.S.(45° 26′ N, 63° 27′ W). The soil at the NSWBI is of the Pugwash series and is described as being a sandy loam free of stone with moderate drainage (Cann *et al.*, 1954). A two-factor factorial experiment was arranged in 4 x 8 m plots in a randomized complete block design and replicated four times. Two metre buffers were included around all sides to minimize drift from one plot to another. The factorial design resulted in four treatment combinations: (a) foliar-applied B at the rate of 300 ppm of Bortrac 150™ (Phosyn Inc., York, England) in 310 $L \cdot ha^{-1}$ of water, (b) soil-applied B at a rate of 2 $kg \cdot ha^{-1}$ B derived from sodium borate fertilizer containing 14.3% B, (c) a combination of the foliar and the soil applications, and (d) a control receiving no B. Foliar treatment applications were made with a carbon dioxide (CO_2) sprayer (R+D Sprayers, Opelousas, La.) at 32 psi with a single, flat-spray nozzle while the granular B fertilizer was applied by hand. The application date was May 20, 1998, following bud break and leaf development in the crop phase of production.

Soil samples were taken prior to applications to quantify the pre-study status of B in the soil. Ten soil cores were taken from each plot using a standard soil probe to a depth of 15 cm. The samples were thoroughly mixed in a bucket and a subsample was taken. Soil samples were taken 1, 2, 4, 8, and 16 days after application (May 20). The samples were assayed for P, K, Ca, Mg, B, Fe and Cu (copper) at the Prince Edward Island Department of

Agriculture and Forestry Laboratory (Charlottetown, P.E.I.) using inductively coupled plasma spectroscopy (ICAP).

After soil sampling, tissue samples were taken to determine the rate of assimilation and allocation of nutrients within the leaves. Leaves were removed from 20 stems randomly selected within each plot. Leaf samples were dried at 60° C for 3 days and ground with a Wiley Mill to pass through a 20-mesh screen. After the samples had been ground, a 1 g +/- 0.0005 g sub-sample was placed in a crucible and pre-ashed for two hours using a hot plate. After pre-ashing the samples were placed in a muffle furnace (Lindberg Hevi-Duty, Watertown, WI) at 500° C for 4 hours. Samples were then digested for 1 hour in 5 mL of 1.0 HCl and transferred to falcon tubes. The total volume was adjusted to 50 mL using deionized water. The samples were centrifuged (International Equipment Company, Needham, MA) at 3000 rpm for 1 hr. Following this, the supernatant was decanted into acid-washed scintillation vials. The tissue samples were also analysed at the Prince Edward Island Department of Agriculture and Forestry Laboratory (Charlottetown, P.E.I.), using the previously mentioned ICAP procedure.

Yield measurements were taken on August 7, 1998, by randomly placing a 1 m^2 quadrat in the plot in an area devoid of any bare patches. All fruit within the quadrat were harvested using a commercial blueberry hand rake. Four quadrats were taken from each plot and weighed using an electronic field balance (Mettler PE 6000, Burlington, ON). The mean of the four measurements from each plot was taken as a yield estimate.

The assumptions of normality, constant variance, and independence were checked using Minitab (Minitab Inc., State College, PA). Analysis of variance was completed in SAS

using Proc GLM (SAS Institute, Cary, NC) to determine if differences in application method were significant. The repeated measures option was used to examine the changes in soil and leaf B levels occurring over the growing season.

2.2.2. Determination of Optimum Time and Frequency of Boron Applications.

Field trials were established at the commercially managed blueberry fields at Wood Islands, P.E.I. (45° 52′ N, 62° 47′ W) and Benvie Hill, N.S. (45° 05′ N, 63° 05′ W). Both fields were primarily composed of *V. angustifolium* clones and were in the crop phase of production during the 1998 growing season. Plots (4 x 8 m) were arranged in a randomized complete block design with 8 treatments and 4 replications. Two metre buffers were included between each plot to prevent spray drift between plots. The treatment combinations were applied at (a) terminal dieback or floral bud initiation stage of the sprout year, (b) at 80% bloom of the crop year, and (c) at fruit set in the following combinations (a, b, c, ab, ac, bc, abc, and control). Boron derived from boric acid (Bortrac 150™, Phosyn Inc., York, England) was applied by a carbon dioxide (CO_2) sprayer (R+D Sprayers, Opelousas, La.) at 32 psi using a single, flat-spray nozzle. The application rate was 300 ppm B in 310 $L \cdot ha^{-1}$ of water.

Approximately 14-21 days after application of foliar-applied B treatments, leaf nutrient levels were assessed by taking leaf tissue samples from 20 plants randomly selected from within each plot. Leaf tissue preparation and analysis was completed using the previously mentioned ICAP protocol (page 22).

To examine yield components, whole-stem samples were gathered from the plots at bud break on April 29 (Wood Islands) and May 5 (Benvie Hill). Twenty stems from each plot

were clipped and placed in water-filled cups in the greenhouse. The number of inflorescences, buds, nodes, and stem length were measured. Floral buds were assayed, using the ICAP protocol (page 22) at this time to determine if B had been translocated from the leaves the previous autumn. Stem samples were gathered in a similar manner at fruit set on June 22 (Wood Islands) and June 24 (Benvie Hill) to observe the yield components. Data were collected on stem and floral zone lengths, the number of nodes, flowering nodes, flowers, and set fruit.

Yield was measured when approximately 90% of the fruit was ripe on August 9 and 11 at Wood Islands and Benvie Hill, respectively. All fruit within a 1 m^2 quadrat were harvested with a commercial hand rake. Four samples were taken from each plot with the mean of the four samples used as a yield estimate. The areas were randomly selected with the restriction that all bare patches were excluded in order to reduce the variability of patch size.

The assumptions of constant variance, normality, and independence were checked using Minitab (Minitab Inc., State College, PA). If the assumptions were violated then the data were transformed using the appropriate transformation. Analysis of variance of the factorial design was completed using the Proc GLM procedure in SAS (SAS Institute, Cary, NC), with the replications at each site being used as blocking factors. If the main effect of application time was found to be significant, the means were separated using Duncan's multiple range test. If interactions of application times occurred means were separated using LSMeans test.

2.3. Results

2.3.1. Efficiency of Soil vs. Foliar-Applications of Boron.

Soil Boron Levels.

Significant differences in soil B levels, as a result of treatment effects, occurred on three of the six sampling dates (Fig. 2.1). The analysis of variance (ANOVA) prior to application (May 20) found that the model was non-significant ($p= 0.5885$), indicating no differences in plots prior to the trial. The mean soil B level for all plots before commencing the study was 0.19 $\mu g \cdot g^{-1}$. The ANOVA model for the first day after application (May 21) was non-significant while the main effect of soil-applied B approached significance ($p= 0.1284$). Three days after application (May 23), the main effect of soil-applied B was significant ($p= 0.0023$). The mean of the soil-applied B treatments was 0.52 $\mu g \cdot g^{-1}$ compared to 0.33 $\mu g \cdot g^{-1}$ in untreated plots. Seven days after application (May 27), the ANOVA model was not significant, however, the effect of the soil-applied B was approaching significance ($p= 0.0603$). The main effect of soil-applied B was significant fifteen days after application (June 4) ($p= 0.0002$), and also at thirty-one days after application (June 20) ($p= 0.0023$). The soil B levels of the treatment receiving foliar-applied B or the control treatment did not change significantly over the course of the sampling period. In all instances where the main effect of soil-applied B was significant, the treatments receiving the soil applications at a rate of 2 $kg \cdot ha^{-1}$ had greater soil B levels than those receiving no granular B. Profile analysis (Appendix 2.5) revealed that the significant change in soil B levels occurred between one (May 21) and three (May 23) days after application. The profile analysis also indicated that the drop in soil B levels measured seven days after application (May 27) was not significantly

different from either the three days after application (May 23) or fifteen days after application (June 4). At the conclusion of the soil sampling period (June 20) the plots that received the soil-applied B treatment (0.48 $\mu g \cdot g^{-1}$) had a soil B level 267% greater than the control plots (0.18 $\mu g \cdot g^{-1}$).

Tissue Boron Levels.

The initial mean leaf B level of all plots was 17.08 $\mu g \cdot g^{-1}$ prior to B applications. Significant differences in B tissue content were present seven, fifteen and thirty-one days after application (Fig. 2.2). The ANOVA model was not significant prior to beginning the study (May 20). It was also non-significant on the day after application (May 21), and three days after application (May 23). However, the main effect of foliar-applied B was significant on May 21 ($p= 0.0202$) and May 23 ($p= 0.0241$). The ANOVA model, however, was not significant. Consequently, these main effects should not be considered to be significant when the whole ANOVA model is non-significant, but these trends should not be disregarded. Visual comparison of the foliar-applied B treatment and the control showed that although non-significant, the foliar application increased leaf B levels the day after application. This increase in leaf B levels compared to the control was maintained throughout the growing season. At the conclusion of the study the leaf B level of the foliar-applied treatment (24.8 $\mu g \cdot g^{-1}$) was 20.9% greater than the control (20.5 $\mu g \cdot g^{-1}$).

The main effect of soil-applied B had a significant effect on tissue B levels on May 27, June 4, and June 20. Those treatments receiving soil-applied B had significantly greater tissue B levels than those not receiving the soil-applied treatment. On the final sampling date

the leaf B level of the soil-applied treatment (114.0 $\mu g \cdot g^{-1}$) was 456% greater than the control (20.5 $\mu g \cdot g^{-1}$).

Yield.

The model for yield was significant (p= 0.073). The only component which was significant (Table 2.1) was the main effect of soil-applied B (p= 0.018). A means comparison was performed using Duncan's multiple range test. This indicated that the yield of plots receiving soil-applied B (482.5 g) was significantly less (i.e., 19%) than those which did not receive soil-applied B (593.2 g).

2.3.2. Determination of Optimum Time and Frequency of Boron Applications.

Foliar Boron Levels.

At Benvie Hill (Table 2.2) there was no significant change in leaf B levels after foliar B applications were made at tip die-back during the sprout year (SY), or at bloom during the crop year (BC). When tissue was sampled following the application at fruit set during the crop year (FC), there was a significant effect of the application at BC and FC. At the BC sample date there were no significant differences in the leaf tissue levels caused the BC application. The main effect of B application at BC was significant (p= 0.0451) when measured at FC. Those treatments that received B had 13% greater B levels (35.9 $\mu g \cdot g^{-1}$) compared to the levels in untreated plots (31.9 $\mu g \cdot g^{-1}$). The main effect of the FC application of B was also significant at the FC sample date (p< 0.0001). The treated plots (39.2 $\mu g \cdot g^{-1}$) were 38% greater than untreated plots (28.5 $\mu g \cdot g^{-1}$).

Blueberry leaf tissue analysis at Wood Islands (Table 2.3) showed no significant effect of B after the SY application. The application at BC was not significant when sampled after the BC application though leaf B levels in plots that received the B application at this time had a greater B concentration (21.0 $\mu g \cdot g^{-1}$) than those not receiving B (17.7 $\mu g \cdot g^{-1}$). Following the application at FC there was a significant effect on leaf B levels due to the main effect of the BC ($p= 0.0476$) and FC ($p< 0.0001$) applications. The application at FC increased B levels in treated plots (35.1 $\mu g \cdot g^{-1}$) by 30% over untreated plots (27.0 $\mu g \cdot g^{-1}$). In all cases those treatments where the plot received B at 300 ppm increased the leaf B level greater than those that received the 0 ppm B treatment.

Vegetative Growth and Yield Components.

The stem length, inflorescence number, flower number, and number of flowers per inflorescence were measured immediately after bud break in the spring of the crop year (Table 2.4). No significant effects of the foliar B applications on stem length, inflorescence number, flower number, and number of inflorescences per stem were found (Table 2.4).

The effect of B applications on the node number and flower number measured at fruit set was not significant (Table 2.5). The effect of B application at BC was found to have a significant effect on stem length (Table 2.5). Those plots not receiving applications at BC had significantly longer stems (17.99 cm) than those receiving the BC application (16.98 cm).

The floral zone length was significantly affected by B application at FC (Table 2.5). Plants in treated plots were 24.2% longer (7.85 cm) compared with untreated plots (6.32 cm). The number of flowering nodes and set fruit were both significantly affected by the

interaction of BC×FC (Table 2.5). It was found that the BC+FC treatment increased the number of flowering nodes by 19% compared with both the application at only BC and at only FC. The combination of BC+FC was not significantly different, but was 8% greater than the control. Fruit set was also improved by the application at both BC and FC. It was 15% greater than the application at BC only and 5% greater than the control treatment.

Dry Matter Accumulation.

The effects of foliar B application on shoot dry matter accumulation indicate a difference in the fresh and dry weight caused by the application of the FC treatment (Table 2.6). The results show that applications at FC increased both dry weights and fresh weights over those not receiving the FC treatment. Fresh weights in plots receiving the FC application (57.25 g) were 10.7% greater than untreated plots. Dry weights in treated plots (19.21 g) were 9.1% greater than untreated plots (17.60 g).

The percent dry matter of the plants (i.e., the dry weight as a percentage of the wet weight) was affected by an SY x BC interaction (Table 2.6). There was a significant difference between those plants not receiving B at either time and those receiving B at either SY and BC. The control had between 5.3% and 9.1% greater dry matter than the other treatments.

Yield and Fruit Size

The effect of foliar-applied B on average berry weight was not significant (Table 2.7) for both sites combined, nor when they were analysed individually. Thus

increases in yield can be attributed to increased berry numbers. The ANOVA model for yield was significant (p= 0.0029) for the two sites combined (Table 2.7). The only component of the model that was approaching significance (p= 0.0562) was the three-way interaction (SY×BC×FC). Upon comparing the means it was observed that the combination of B at SY and BC and no B at FC gave the highest yield. It did not differ significantly from the control but did increase yield by 15.6%.

At Wood Islands, the yield was significantly affected by the three-way interaction (Table 2.7). The applications of B at both SY and BC increased yield by 16% compared to the control treatment. At Benvie Hill, although the ANOVA model was non-significant, the highest yielding treatment was B application at SY and BC (Table 2.7). This treatment yielded 15% greater than the control treatment.

2.4. Discussion

2.4.1. Efficiency of Soil vs. Foliar-Applications of Boron.

Soil Boron Levels.

Soil-applied B treatments caused significant changes in soil B levels during the growing season. As anticipated, the foliar B applications had no effect on soil B levels. The mean soil B in all plots prior to application at the N.S.W.B.I., Debert, N.S. was 0.19 $\mu g \cdot g^{-1}$. Leaf tissue nutrient analysis provides the most accurate and precise assessment of the nutritional status of a blueberry field (Trevett *et al.*, 1968). The field was determined to be B deficient as a result of the mean leaf B level of all plots being 17.1 $\mu g \cdot g^{-1}$. The mean leaf B level of the control plot was never greater than 20.5 $\mu g \cdot g^{-1}$ throughout the course of the study. These levels were well below the crop year standard of 30 $\mu g \cdot g^{-1}$ given by Trevett (1972) for crop fields. Soil-applied B increased soil levels by 267% in treated plots (0.48 $\mu g \cdot g^{-1}$) compared with untreated plots (0.18 $\mu g \cdot g^{-1}$) ppm. Application of granular B fertilizer increased the soil B but it appears to an ineffective method. Problems with B toxicity and the lag between application and uptake seem more likely to occur using granular applications.

The granular B fertilizer application significantly increased B levels in the soil on three of the six sampling days. On May 27, seven days after application, there was no significant effect of soil-applied B on soil B levels. This was probably an indication of the inconsistencies that can occur when sampling soil B levels shortly after application. Neilsen *et al.* (1985) found variability in soil B levels in peach orchards in British Columbia when B was applied in granular form.

Effect of Soil Characteristics.

The soil at the Nova Scotia Wild Blueberry Institute (NSWBI) is of the Pugwash series. It is a moderately drained coarse loamy till and is typically, free of stone. These characteristics make this soil quite susceptible to leaching. The final soil sample taken indicated that B levels were beginning to decline. Possible explanations for this were either uptake by the plant or leaching. The most plausible explanation was a combination of the two factors. Boron is most available to plants at lower pH's (Gupta, 1979). As it is more available in the soil solution, it is more easily assimilated and leached than if it were bound to soil particles. This helps explain why B uptake was greater than anticipated. The total soil B would decrease rapidly because conditions were conducive for both leaching and uptake. Further sampling later in the growing season and more frequently may have helped determine the cause and given a better indication of the nature of this trend.

Boron Leaf Levels.

Although quantifying soil B levels provides some understanding to the effects of leaching and uptake on soil B levels, the efficacy of B applications is best determined by the effect on tissue B levels. Trevett (1972) suggested the minimum B level in leaf tissue be 24 ppm in the sprout year and 30 ppm in the crop year. A survey conducted by Smagula (1993) in Maine in 1987 and 1988 found 39 of 75 fields sampled had leaf B levels below the minimum standard. Plots that received B by soil applications to relieve deficiency had tissue B levels greater than 100 $\mu g \cdot g^{-1}$, well over the upper tissue B level standard for the crop year of 40 $\mu g \cdot g^{-1}$ (Trevett *et al.*, 1968). The application rate (2 kg $B \cdot ha^{-1}$) was thought to be

sufficient and fairly safe for lowbush blueberries. These results reflect the problems associated with using soil-applied B on sandy soils. The increased B availability results in greater levels in the leaf tissue leading to B toxicity (Gupta, 1979). It appears that it is difficult to accurately increase the B level into the range of sufficiency.

Reports from work conducted in sour cherry (Hanson, 1991) and highbush blueberries (Blevins *et al.*, 1996) indicate that although tissue B levels may be within an acceptable range, foliar-applications of B can improve yields. Although the effect of foliar B was non-significant, the foliar-applied B treatment augmented leaf B levels over the control by approximately 4 $\mu g \cdot g^{-1}$. This trend was maintained throughout the duration of the study and it appears that foliar applications are the best method to safely increase tissue B levels.

The application rate is probably the greatest reason for the lack of response in leaf B levels. Chen *et al.* (1998), working with lowbush blueberries in Maine, used levels of 345 g $B \cdot ha^{-1}$ in studies to remedy B deficiency. The level (93 g $B \cdot ha^{-1}$) used in this study was selected based on preliminary work conducted at the Nova Scotia Agricultural College. Using a higher application rate might have produced a significant effect, though discretion must be exercised as concentrations of 900 ppm or higher have resulted in foliar burn (Ju, 1987; Percival, personal communication). Although improvements were noted in tissue B status, the application rate was not great enough to increase leaf B levels into the range of sufficiency.

Efficiency of Foliar Boron Application.

Boron is important in the growth of the pollen tube and fruit set (Chen *et al.*, 1998).

Boron deficiency has been noted as a cause of grain set failure in wheat as it results in the improper development of pollen and anthers in wheat (Cheng and Rerkasem, 1993). Pollen tube growth is an extremely short-lived event, approximately 7-10 days. The time period when the pollen tube can be stimulated is brief. Therefore, application of B solely by soil could result in missing the critical period. However, B is especially dependent upon moisture for assimilation. In a dry season the nutrients may not be available to the plant until the need for them has subsided. Research conducted by Delgado *et al.* (1994) found a requirement for B at anthesis could be met by foliar applications.

Meanwhile, despite the fact soil-applied B significantly increased B levels it was also an inefficient method of application. Soil B levels were not increased until the third sampling date (May 23). On May 22, 15.25 mm of rain fell in the Debert area, which was responsible for the soil B to be increased on the next sample day. This increase in soil B levels was not noted in leaf tissue analysis until the fourth sampling date (May 27). The lag that occurred between application and the increase in tissue B levels, coupled with the difficulty in determining the proper application rate make soil-applied B inefficient for providing B to all plant parts when needed for specific growth processes.

Assimilation and Allocation.

It was hoped that this study would confirm how B is assimilated by the plant whether it be by the phloem or by the xylem. Boron uptake occurs primarily by way of the transpiration stream, movement of B via the phloem is restricted in most plants (Shelp *et al.*, 1995). The lag that occurred between application and B being washed into the soil prevented

this from being determined. If there were an active component in B assimilation than the increase in leaf levels would have been expected to occur rapidly. The best method of determining the method of allocation and assimilation is with the use of radio-labelled B. Boron isotopes have been used successfully in other crops to determine the mode of assimilation and distribution within the plant (Picchioni *et al.*, 1995). Such research should be conducted using the lowbush blueberry.

Form of Boron Application.

The results of this study indicate that foliar B applications have merits in commercial blueberry production. It appears that foliar application rates greater than 93g $B \cdot ha^{-1}$ are needed and are likely to be beneficial. Perhaps the development of the cuticle and waxy layer on the blueberry leaves was greater than when the preliminary work to determine the proper rate was conducted at the Nova Scotia Agricultural College. The development of the cuticle affects the rate of assimilation by the leaves (Marschner, 1997) and the thickness may vary at different growth stages and due to various environmental conditions. This presents difficulties in ensuring that uptake is consistent from year to year and in different climatic conditions.

A study conducted by Smagula (1993) using Solubor showed that in clones determined to be B deficient, applications of B at 400 ppm increased yield significantly. Boron sprays in this study were applied during the sprout year. The impact on pollen tube growth would not have been as great as if it were applied directly to the developing flower at bloom. Previous experiments using concentrations as high as 10,000 ppm showed severe

chlorosis and reduced fruit yield (Ju, 1987). Preliminary studies conducted prior to this research indicated that foliar burn occurred when B levels were as low as 1000 ppm.

Other nutrient levels did not appear to change significantly due to the application of the treatments. There was the occasional day that nutrients changed significantly but this is most likely due to seasonal growth changes or caused by variation due to sampling.

Yield.

The response in determining which application method is most promising is the effect on crop yield. The results indicated that yield was affected by the main effect of soil-applied B. Those treatments that received soil-applied B were decreased by 18.7% compared to those not receiving the application. The yield decrease can best be attributed to B toxicity, indicating that the application rate was too high. In other studies investigating B toxicity authors found similar yield reduction in lettuce (Francois, 1988) and tomatoes (Francois, 1984). A further clue in favour of foliar applications, though non-significant, is foliar treatments of B produced yields 8.8 % higher than the control. It would be interesting to determine if the effect would be significant if a higher application rate were used.

Modifications to Methods.

Applying granules by hand may also have had a role to play in causing the variation. The application rate of 2 $kg \cdot ha^{-1}$ of granular B was so small that it was not feasible to apply the fertilizer with a spreader. It would also have been difficult to ensure a proper calibration

and that all of the granules fell within the plot. The best method of application would have been to mix it with a filler and then apply it using a spreader.

2.4.2. Determination of Optimum Time and Frequency of Boron Applications.

Boron Applications in the Sprout Year.

The foliar B applications made at the three different growth stages (SY, BC, FC) produced similar results in leaf B levels at the two locations. Applications of foliar-applied B at Wood Islands, P.E.I. resulted in no significant differences after the SY treatment. Similar results were observed for Benvie Hill, N.S. Smagula (1993) applied foliar B sprays in a study in Maine and found a significant response in leaf tissue sampled the following summer. This response was greatest at application rates of 400 and 600 ppm. The reason behind this may be the 300 ppm concentration used in this study was not sufficiently high enough to produce a response. Perhaps the application rate was not great enough at tip dieback to produce a response. At that stage in the development of the lowbush blueberry the plant has developed a waxy cuticle that would suppress uptake. Another factor that may play a role is that application were made near midday when the stomata may begin to close. Chen *et al.* (1998) report that there is interclonal variation in their initial B status and in their rates of assimilation. This inherent variation may have masked the uptake to some degree. The boron levels in the control plots at Benvie Hill (29.1 $\mu g \cdot g^{-1}$) and at Wood Islands (25.2 $\mu g \cdot g^{-1}$) were both greater than the 24 ppm standard for the sprout year.

The B level in the fruit buds was not significantly changed by B application at SY when sampled the following spring (Appendix 3.17). This contradicts the findings of Chen

et al. (1998) who worked with individual clones, perhaps explaining the discrepancies. The whole bud was sampled making it difficult to determine whether the B concentration near the floral primordia increased, since the bulk of the sample was the hull of the bud. In a study conducted by Smagula (1993), it was found that B was translocated from the leaves to the developing buds. Perhaps the greater response detected was a factor of improved translocation by working with clones known to be B deficient. In this study the foliar B application was made even later than in our study when uptake would be expected to decrease due to an increased cuticle thickness and lower metabolic rate.

Boron Applications in the Crop Year.

The applications made at 80% bloom of the crop year (BC) did not significantly increase leaf B levels at Benvie Hill or at Wood Islands. The application at BC resulted in increased leaf B levels at both locations. The BC application did not increase tissue B levels above the crop year standard of 30 ppm (Trevett, 1972). Applications were made early in the morning when stomata would be open allowing for maximum uptake.

The application of B at fruit set of the crop year (FC) resulted in increased B levels due to the main effect of the FC application at both locations. After the FC sampling there was a significant effect of the BC application noted at both Benvie Hill and Wood Islands. This indicated that the application made at BC was carried over later into the crop year. The reason for the BC application not being significant until after the FC sampling can be attributed to the few degrees of freedom available to estimate the error variance. Since it was a factorial experiment where time was a factor and samples were taken prior to all treatments

being applied, the error degrees of freedom increased as the study progressed. This coupled with the clonal variation that exists in blueberries was responsible for not detecting the response. Obviously, the B must have entered the plants at BC, and from Study 1, it was noted that the effects of foliar-applied can be seen within 24 hours. The significance of the BC application being detected at FC is that the B was assimilated by the plant and was in the leaf tissue. Thus the BC application led to increased B status throughout the season at both sites.

At Benvie Hill, the treatment applied at FC led to B tissue levels ranging between 37.5-43.8 $\mu g \cdot g^{-1}$, compared with 24.4-34.4 $\mu g \cdot g^{-1}$ in untreated plots. At Wood Islands plots receiving the FC treatment had leaf B levels between 32.0-36.0 $\mu g \cdot g^{-1}$ while untreated plots ranged between 24.3-28.2 $\mu g \cdot g^{-1}$. This suggests that the application at FC in some treatment combinations was beginning to approach the upper limit of B concentration in leaf tissue of 40 $\mu g \cdot g^{-1}$. At this level, it would be likely to see effects of toxicity.

Yield Components.

No significant effect attributable to the SY application was found on the stem length, number of inflorescences, flower number or flowers per inflorescence. This indicated that there was no effect of B applications at tip dieback of the sprout year on the floral development the following spring. Differences might have been difficult to detect due to the mild winter of 1997-98 and the diverse clonal populations that are present. Chen *et al.* (1998) found no significant effect of B on the number of flowers per bud.

The effect of B applications on the node number and flower number measured at fruit

set was not significant. The floral zone length was significantly affected by the FC application. Treated plots had floral zones 24.2% longer (7.85 cm) compared with untreated plots (6.32 cm). The number of flowering nodes and fruit set were both significantly affected by the interaction of BC×FC. The treatment at both BC and FC produced 19% more flowering nodes than the application at only BC and at only FC (Table 2.5). The number of flowering nodes in the BC and FC application were not significantly different from each other, but were 8% greater than the control (Table 2.5). The number of set fruit was also improved by the application at both BC and FC. It was 15% greater than the application at BC only and 5% greater than the control treatment (Table 2.5). These increases in yield components suggest an effect of the FC application on yield components. However these variables were measured shortly after the application at FC was made. It would not be expected that the number of flowers or floral zone length would be affected at this point in lowbush blueberry development. Smagula (1993) and Chen *et al.*, (1998) found no effect of autumn B application on fruit set. Hanson and Breen (1985) concluded that autumn applications increased fruit set in years when set was low; these effects were not detected in years where set was high.

Chen *et al.* (1998) used tagged stems throughout the season to determine the effects on yield components. In our study, whole stem samples were collected at the different sampling periods. This destructive sampling method may explain why there were some inconsistencies in the results. Using the tagged stems would have reduced variability between the stems sampled at different growth stages. This variability was not anticipated and the reason for the whole-stem sampling was practicality.

Dry Matter Accumulation.

In this study dry weights and fresh weights were greatest in plots that received the FC application. Fresh and dry weights were determined using the stems collected after the FC application that were used in determining fruit set. The fruit set was greatest in the treatments that received the BC and FC application. The increase in dry and fresh weights was not likely attributable to increased fruit as application at FC generally decreased yield. It is best explained by a shift in the carbon allocation from reproductive development to vegetative growth. The percent dry matter was affected by the SY × BC interaction. The percent dry matter was greatest in the treatment not receiving the SY or BC treatments. This may be explained by the decreased yield in this treatment, berries would be sinks for moisture and would lose more weight through drying than vegetative growth (i.e., stems and leaves). These findings contradict those of Hanson (1991), who found that B applications at fruit set increased the percent dry matter.

Yield.

The increase in yield was found to be greatest in those plots receiving the SY x BC application. Smagula (1993) found increases in berry yield with autumn treatments of B applied at 400 and 600 ppm; these treatments yielded 51.8 % and 23.5 % greater than the control, respectively. In 3 of 5 clones examined, the yield increase was attributed to greater number of berries, greater berry diameter and improved fruit set (Smagula, 1993). The effect of foliar B sprays is usually not seen when overall fruit set is quite good. In 'Italian' prune when fruit set was low, foliar B application increased fruit set and yield (Hanson and Breen,

1985). Shrestha *et al.*, (1987) found improved fruit set and yield in all treatments, when B was applied once in the autumn and 5 times throughout the spring and summer.

In highbush blueberries autumn foliar applications resulted in decreased incidences of winter injury (Blevins *et al.*, 1996). This may be the reason for increased yield due to the SY + BC applications compared with the control. However, in the Maritimes during in the 1998 crop year, there was very little winter injury. This was due to adequate snow cover which provided an insulating layer to plants and few incidences of freezing and thawing which reduce bud survival. A greater response to the SY application is anticipated in seasons when winter injury is more severe.

In this experiment fruit size was not affected by the foliar B applications (Table 2.7). In this instance, because yield increased and there was no effect attributed to the berry size, increased berry numbers must have been responsible for the change in yield. However this assumption may not be valid based on the findings of Smagula (1993) who found increases in yield but could not significantly attribute them to either berry number or berry size. A study in cranberries concluded that an application of B and Ca resulted in increased yield attributable to increased berry number (DeMoranville and Deubert, 1987). Chen *et al.* (1998), found no increase in berry yield due to autumn B applications.

Based on these results, the optimum time and frequency of application is at tip dieback of the sprout year and at bloom of the crop year. Yield increases due to this combination of applications could be explained by improved winter injury and improved development of the pollen tube during the fertilization process. It was difficult to attribute increases in yield to increases in particular yield components. There were contradictory results when yield

components were sampled at different growth stages. This problem could be alleviated by using the same tagged stems throughout an entire growing season. Using this method, the same stem could be observed throughout the entire season to reduce the variation between stems. Problems might occur if the stem were damaged due to biotic or abiotic factors. It is quite time consuming and may be inconvenient if much travel is required to reach the field.

2.5. Conclusions and Summary

The comparison of foliar B applications with soil B applications indicates there are numerous advantages to foliar-applied B. The use of foliar applications can increase tissue B levels more rapidly than soil applications and there is no leaching problem with foliar applications. It appears to be much easier to augment the tissue B levels via foliar applications without encountering toxicity problems. Foliar B applications did not improve leaf B levels significantly. But this is felt to be more a factor of a low application rate rather than ineffectiveness of foliar sprays. Though it was not significant, yield was greater in the foliar-applied B plots than in the control, providing some indication further work is needed to determine the full potential of foliar B use.

Further study of the dynamics of B uptake and assimilation is needed to determine the mode of allocation. Foliar-applied B applications hold more promise than granular fertilizers to quickly alter nutrient levels. Critical stages in plant development such as the fertilization and pollination processes occur over a brief period of time and may be enhanced by supplemental B applications. The use of radio-labelled B should be considered to determine the allocation dynamics and probably should have preceded this study.

Applications at bloom and fruit set of the crop year were most effective increasing leaf B levels. The sprout year applications did not increase B levels in either the leaf tissue or the buds the following spring. Yield components were not affected by the SY application but were affected by the BC and FC treatments. The results were inconsistent, making it difficult to attribute yield increases to changes in particular yield components.

The results of this study suggest that applications in both the crop and sprout year are

necessary to maximize yield. The combination producing the greatest yield was application at SY and BC, 15.6% greater than the control. The most promising time for application to improve blueberry yields was the SY + FC application which increased yield at both sites. The effects of B on winter survival were not as pronounced as expected. A mild winter and spring may have reduced the potential impact of the SY treatments but the increase in yield suggests that there may have been an effect. Further study needs to be conducted to determine the tolerance of lowbush blueberry treated with foliar B to winter injury. However, the results from the leaf tissue sampling in the sprout year did not indicate an increase leaf B level. The seasonal variation in metabolic activity coupled with development of the plants cuticle over the growing season may require different concentrations at various times.

Based on 1999 costs, the application of foliar-applied B during the sprout year and prior to bloom would require a yield increase of 40-50 $kg \cdot ha^{-1}$ to cover the cost of the product only. In this study, the application at SY and BC resulted in an increase of 1130 $kg \cdot ha^{-1}$ compared with the control at both sites combined. If the yield increases were consistent, producers would have to compare other costs associated with application with the increased revenue in order for it to be a viable management practice.

Before adopting this as a management practice, these results must be reproduced both spatially and temporally. Further consideration must also be given to the effects of added B on the availability of other nutrients. There are a number of interesting interactions that occur between B and other nutrients especially the interactions of B with Ca and Mg.

Table 2.1. Yield of lowbush blueberries as influenced by the application of soil and/or foliar-applied B during the crop phase of production (1998) at the Nova Scotia Wild Blueberry Institute, Debert, N.S.

Treatment[z]		Yield[y] ($g \cdot m^{-2}$)
- Soil B[x]	- Foliar B[w]	569.3
- Soil B	+ Foliar B	617.3
+Soil B	- Foliar B	509.9
+Soil B	+ Foliar B	455.0
ANOVA Results[v]		Soil*

[z] Both soil and foliar B treatments were applied May 20, 1998.

[y] Plot yields were estimated by taking the mean of 4-$1 m^2$ subsamples harvested from each plot on August 7, 1998.

[x] Soil B treatments consisted of granular Na_2BO_7 ($2 kg \cdot ha^{-1}$).

[w] Foliar B treatments consisted of Bortrac 150 (300 ppm in 310 $L \cdot ha^{-1}$ of water).

[v] Data were analysed as a 2^2 factorial design. Analysis of variance results indicate that factors were either non-significant (NS) or significant (*,**,***) at P< (0.05, 0.01, and 0.001), respectively.

Table 2.2. Boron concentrations in lowbush blueberry leaf tissue following foliar B applications in the sprout (1997) and crop (1998) phases of production at Benvie Hill, N.S.

Time of application[z]			Leaf B levels ($\mu g \cdot g^{-1}$)[y]		
SY	BC	FC	Sample 1 (SY)	Sample 2 (BC)	Sample 3 (FC)
-	-	-	32.9	24.8	24.4
-	-	+			37.5
-	+	-		25.1	34.1
-	+	+			43.8
+	-	-	36.9	24.5	30.4
+	-	+			35.2
+	+	-		24.3	25.2
+	+	+			40.3
ANOVA Results[x]			NS	NS	BC* FC***

[z] Foliar B treatments of Bortrac 150 at a rate of 93g B·ha^{-1} (300 ppm in 310 L·ha^{-1} of water) were applied at tip dieback - sprout year (SY), prior to bloom - crop year (BC), and prior to fruit set - crop year (FC).

[y] Tissue samples, comprised of foliage from 20 stems·plot^{-1}, were taken approximately 14 days after application.

[x] Data were analysed as a 2^1, 2^2, and 2^3 factorial at SY, BC, and FC, respectively. Analysis of variance results indicate that factors were either non-significant (NS) or significant (*,**,***) at P< (0.05, 0.01, and 0.001), respectively.

Table 2.3. Boron concentrations in lowbush blueberry leaf tissue following foliar B applications in the sprout (1997) and crop (1998) phases of production at Wood Islands, P.E.I.

Time of application[z]			Leaf B levels ($\mu g \cdot g^{-1}$)[y]		
SY	BC	FC	Sample 1 (SY)	Sample 2 (BC)	Sample 3 (FC)
-	-	-	25.2	17.7	27.8
-	-	+			32.0
-	+	-		20.6	27.8
-	+	+			38.7
+	-	-	27.3	17.4	24.3
+	-	+			33.8
+	+	-		23.4	28.2
+	+	+			36.0
ANOVA Results[x]			NS	NS	BC* FC***

[z] Foliar B treatments of Bortrac 150 at a rate of 93g B·ha^{-1} (300 ppm in 310 L·ha^{-1} of water) were applied at tip dieback - sprout year (SY), prior to bloom - crop year (BC), and prior to fruit set - crop year (FC).

[y] Tissue samples, comprised of foliage from 20 stems·plot^{-1}, were taken approximately 14 days after application.

[x] Data were analysed as a 2^1, 2^2, and 2^3 factorial at SY, BC, and FC, respectively. Analysis of variance results indicate that factors were either non-significant (NS) or significant (*,**,***) at P< (0.05, 0.01, and 0.001), respectively.

Table 2.4. Effect of time and frequency of foliar-applied B treatments on the vegetative growth and reproductive yield components of lowbush blueberries at two combined locations (Benvie Hill, N.S. and Wood Islands, P.E.I.) in 1998.

Time of application [z] SY	Stem length [y] (cm)	Inflorescences per stem	Flowers per stem	Flowers per inflorescence
-	18.7	6.40	29.70	4.39
+	17.6	6.64	31.83	4.66
ANOVA Results [x]	NS	NS	NS	NS

[z] Foliar B treatments of Bortrac 150 at a rate of 93g B·ha^{-1} (300 ppm in 310 L·ha^{-1} of water) were applied at tip dieback - sprout year (SY), prior to bloom - crop year (BC), and prior to fruit set - crop year (FC).

[y] Tissue samples, comprised of foliage from 20 stems·plot^{-1}, were taken approximately 14 days after application

[x] Data were analysed as a 2^1, 2^2, and 2^3 factorial at SY, BC, and FC, respectively. Analysis of variance results indicate that factors were either non-significant (NS) or significant (*,**,***) at P< (0.05, 0.01, and 0.001), respectively.

Table 2.5. Effect of time and frequency of foliar-applied B treatments on the vegetative growth and reproductive yield components of lowbush blueberries at two combined locations (Benvie Hill, N.S. and Wood Islands, P.E.I.) in 1998.

Time of application[z]								
SY	BC	FC	Stem[y] length (cm)	Nodes per stem	Flowering nodes per stem	Floral zone length (cm)	Flower number per stem	Set fruit per stem
-	-	-	17.98	21.43	5.81	6.30	21.78	20.34
-	-	+	18.28	17.23	5.29	8.12	20.29	18.56
-	+	-	17.24	19.88	4.74	5.03	18.11	17.00
-	+	+	16.71	20.03	6.23	7.92	23.14	21.64
+	-	-	17.20	21.14	5.54	6.43	20.81	19.11
+	-	+	18.52	22.62	4.96	8.03	19.51	17.16
+	+	-	16.88	18.63	5.56	7.55	21.44	19.61
+	+	+	17.12	20.61	6.02	7.32	21.65	19.54
ANOVA Results[x]			BC**	NS	BC×FC**	FC*	NS	BC×FC**

[z] Foliar B treatments of Bortrac 150 at a rate of 93g B·ha^{-1} (300 ppm in 310 L·ha^{-1} of water) were applied at tip dieback - sprout year (SY), prior to bloom - crop year (BC), and prior to fruit set - crop year (FC).

[y] Values are on a per stem basis, 20 stems per plot were sampled on June 22 and June 24 (after FC) at Wood Islands, P.E.I. and Benvie Hill, NS respectively.

[x] Data from both locations were combined and analysed as a 2^3 factorial in 8 blocks. Analysis of variance results indicate that factors were either non-significant (NS) or significant (*,**,***) at P<(0.10, 0.05, and 0.01), respectively.

Table 2.6. Effect of time and frequency of foliar-applied B treatments on dry matter accumulation of lowbush blueberries at two combined locations (Benvie Hill, N.S. and Wood Islands, P.E.I.) in 1998.

Time of application[z]					
SY	BC	FC	Fresh weight[y] (g)	Dry weight (g)	Dry matter (%)
-	-	-	53.36	18.64	37.69
-	-	+	58.92	20.48	36.85
-	+	-	51.05	17.59	36.09
-	+	+	56.85	18.10	32.80
+	-	-	52.61	17.35	34.08
+	-	+	58.69	19.83	34.28
+	+	-	49.81	16.81	35.48
+	+	+	54.53	18.41	35.34
ANOVA Results[x]			FC**	FC**	SY×BC*

[z] Foliar B treatments of Bortrac 150 at a rate of 93g B·ha^{-1} (300 ppm in 310 L·ha^{-1} of water) were applied at tip dieback - sprout year (SY), prior to bloom - crop year (BC), and prior to fruit set - crop year (FC).

[y] Values are the mass of 20 stems per plot sampled on June 22 and June 24, 1998 (after FC) at Wood Islands, P.E.I. and Benvie Hill, NS, respectively.

[x] Data from both locations were combined and analysed as a 2^3 factorial in 8 blocks. Analysis of variance results indicate that factors were either non-significant (NS) or significant (*,**,***) at P< (0.10, 0.05, and 0.01), respectively.

Table 2.7. Yield and berry weight of lowbush blueberries as influenced by time and frequency of foliar-applied B treatments at Benvie Hill, NS and Wood Islands, P.E.I. in 1998.

Time of application[z]			Yield[y] ($g \cdot m^{-2}$)			Average[x] berry weight ($g \cdot berry^{-1}$)
SY	BC	FC	Combined[w]	Benvie Hill[v]	Wood Islands	Combined
-	-	-	723.1 ab[u]	736.0	710.2 ab	0.38
-	-	+	748.9 ab	807.7	690.1 ab	0.35
-	+	-	644.6 b	635.5	653.8 ab	0.36
-	+	+	708.0 b	747.3	668.6 ab	0.34
+	-	-	682.8 b	736.3	629.4 ab	0.34
+	-	+	730.1 ab	740.7	719.6 ab	0.34
+	+	-	836.1 a	848.2	823.9 a	0.34
+	+	+	635.5 b	729.3	541.7 b	0.36
ANOVA Results[w]			SY×BC×FC*	NS	SY×BC×FC*	NS

[z] Foliar B treatments of Bortrac 150 at a rate of 93g $B \cdot ha^{-1}$ (300 ppm in 310 $L \cdot ha^{-1}$ of water) were applied at tip dieback - sprout year (SY), prior to bloom - crop year (BC), and prior to fruit set - crop year (FC).

[y] Plot yields were estimated by taking the mean of 4-$1 m^2$ subsamples harvested from each plot on August 9, and August 11, 1998 at Wood Islands, P.E.I. and Benvie Hill, NS.

[x] Individual berry weights were determined by massing 50 berries from each plot and determining the average mass.

[w] Data from both locations were combined and analysed as a 2^3 factorial in 8 blocks. Analysis of variance results indicate that factors were either non-significant (NS) or significant (*,**,***) at P< (0.10, 0.05, and 0.01), respectively.

[v] Yield data from each site were also analysed individually as a 2^3 factorial. Analysis of variance results indicate that factors were either non-significant (NS) or significant (*,**,***) at P< (0.10, 0.05, and 0.01), respectively.

[u] Means separation was conducted using LSMeans, values with the same letter are not significantly different from each other.

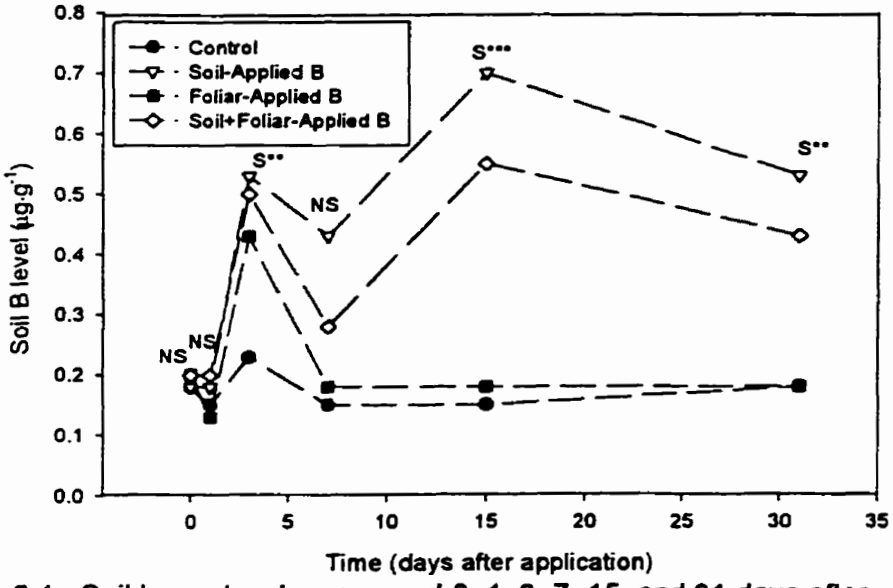

Figure 2.1. Soil boron levels measured 0, 1, 3, 7, 15, and 31 days after application (May 20) of soil-applied and foliar-applied boron at the N.S.W.B.I., Debert, N.S., during the crop phase of production. Factors were either non-significant (NS) or significant (*,**,***) at p< (0.05, 0.01, 0.001), respectively.

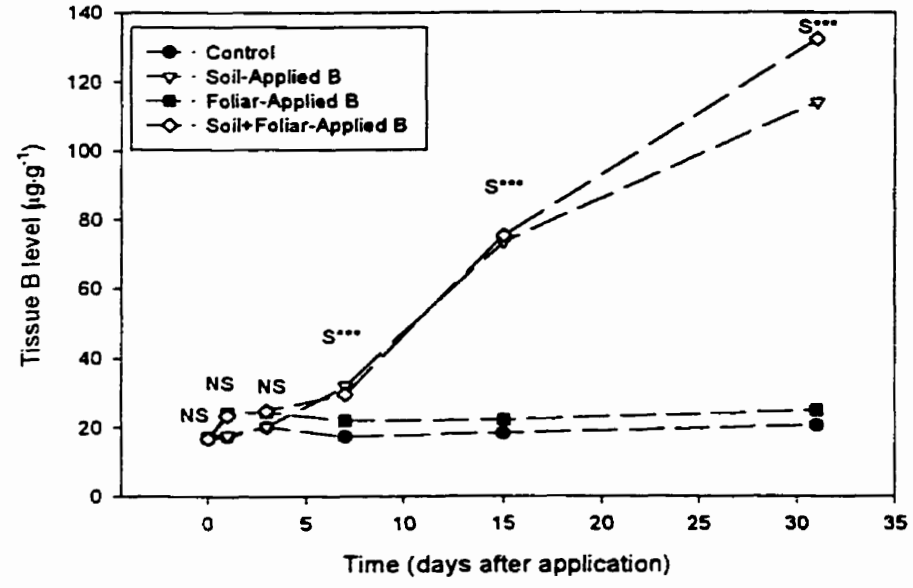

Figure 2.2. Tissue boron levels measured 0, 1, 3, 7, 15, and 31 days after application (May 20) of soil-applied and foliar-applied boron at the N.S.W.B.I., Debert, N.S., during the crop phase of production. Factors were either non-significant (NS) or significant (*,**,***) at p< (0.05, 0.01,0.001), respectively.

CHAPTER 3 - Main and Interactive Effects of Boron, Calcium, and Magnesium on Vegetative and Reproductive Components of Lowbush Blueberry.

ABSTRACT

The main and interactive effects of foliar-applied B, Ca and Mg on winter injury, mineral nutrition, vegetative growth and reproductive yield components of lowbush blueberry (*Vaccinium angustifolium* Ait.) were investigated at a commercial site in Lynn Mountain, NS during 1997 (sprout year) and 1998 (crop year). Bortrac 150, Caltrac and Hydromag were applied at various rates as specified by orthogonal treatment combinations of the central, composite design. Two centre points (350 ppm of B, 4000 ppm of Ca and 1000 ppm of Mg in 310 $L \cdot ha^{-1}$) were included in each of the three replications. Applications were made with a CO_2 sprayer at the black tip stage of the sprout year, and half of each plot was sprayed again at 80% bloom during the crop year. Plant nutrient (P, K, Ca, Mg, B, and Cu) levels were near sufficient when determined in both the crop and sprout years. Zinc levels were near the low end of the sufficiency range though they were never less than the critical standards of 5.8 and 7.0 $\mu g \cdot g^{-1}$ in the sprout and crop years, respectively. Winter injury of the terminal bud was marginally promoted by B, whereas Ca increased winter survival of the vascular tissue. There was no significant difference in yield or berry size between once and twice-sprayed plots. The number of inflorescences per stem was increased by Ca applications but was not correlated with yield. Yield was significantly affected by applications of B and Mg. Using response

surface methodology a predictive equation using coded values [$y = 374.6 + 55.88\,(Mg) + 56.2\,(B^2)$] was developed to estimate yield in the twice-sprayed plots. Boron was responsible for the differences in berry weight which was correlated with yield in twice sprayed plots. Therefore, foliar nutrient applications can improve the yield of lowbush blueberries. However, to maximize efficiency further research is needed to examine these interactions in conjunction with the optimum time of application.

3.1. Introduction

Developing a fertility program for optimizing nutrient application rates to provide plants with adequate nutrition while minimizing costs and environmental impacts is a difficult task. May and Pritts (1993) cite four reasons for this difficulty: i) there is genetic variability in the requirement of species and within species, ii) there are 12 nutrients necessary for plant growth, iii) nutrient availability is affected by environmental conditions and iv) nutrients interact among themselves. Interactions between mineral nutrients in plants are of particular importance when at least one of the nutrients is near toxicity or deficiency (Marschner, 1997). These interactions can be either beneficial or detrimental depending on the nutrients involved, their relative concentrations and how they interact (Marschner, 1997). Understanding the nature of these interactions and their subsequent effects are fundamental in developing fertility programs.

In lowbush blueberry research, fertility management studies have focussed on the macronutrients nitrogen (N) (Smagula and Hepler, 1980; Eaton and Patriquin, 1988), phosphorus (P) (Smagula and Dunham, 1995; Warman 1988) and potassium (K) (Warman, 1988; Trevett *et al.*, 1968). However, little research has been done to determine the effects of the other essential nutrients such as calcium (Ca) and magnesium (Mg), which have both been shown to interact with boron (B) (DeMoranville and Deubert, 1987; Yogaratnam and Johnson, 1982; Chen *et al.*, 1998; Reinbott and Blevins, 1995).

Calcium is absorbed by the plant in the form of the calcium ion (Ca^{2+}) and is assimilated by the plant mainly by mass flow and secondly by root interception (Gardner *et al.*, 1985). Calcium is required for cell division and cell elongation and is an essential

component of cell membranes (Mengel and Kirkby, 1987). It does not affect the process of photosynthesis as directly as other elements (Natr, 1992). Calcium is an integral part of the cell wall structure and affects the strength of plant tissue (Mengel and Kirkby, 1987). Another important function of calcium is as a constituent of calmodulin; an integral part of the plant's signalling system that mediates responses to environmental conditions (Bootman and Berridge, 1995).

Magnesium is assimilated by plants by way of mass flow (Gardner *et al.*, 1985). A smaller portion of magnesium is assimilated by root contact, and there is little if any uptake by diffusion (Gardner *et al.*, 1985). Unlike B and Ca, Mg is taken into plants both actively and passively. Similar to B and Ca, transport occurs mainly through the transpiration stream (Mengel and Kirkby, 1987). However, Mg is more mobile within the plant than B and Ca (Marschner, 1997). Retranslocation of Mg from older tissues is necessary to provide younger organs with an adequate supply if the developing tissues are deficient (Mengel and Kirkby, 1987). One of the most important functions of Mg in plants is its role as the centre of the chlorophyll molecule. Approximately 25% of the total Mg content in plant leaves is as a constituent of chlorophyll (Dreyer *et al.*, 1994).

There are several advantages to applying Ca and Mg to lowbush blueberries via foliar applications. These nutrients, like B, are often bound to organic matter and Fe and Al hydroxides when applied to the soil (Gupta *et al.*, 1985). Although Ca is similar to B as it is quite mobile in the soil and is easily leached (DeMoranville and Deubert, 1987), once assimilated into a plant, there is little or no movement in the phloem (Gardner *et al.*, 1985). Another concern with soil applications is that blueberries have adapted to growing in soils

with a pH range between 4.0-5.0. At such low pH's the availability of B, Ca and Mg is reduced (Marschner, 1997). Foliar applications may help alleviate these problems and may be the most economically and environmentally sound method.

Foliar applications of B, Ca and Mg have had varying effects on other crops. Boron and Ca applied together have increased yields in cranberries (DeMoranville and Deubert, 1987) and have enhanced the colouration of apples. Individual B treatments have increased the incidence of cracking in non susceptible apple varieties (Yogaratnam and Johnson, 1982) and have both independently and synergistically increased pollen germination on the stigmata compared with control treatments in blueberries (Chen *et al.*, 1998). Foliar-applied B and Mg have increased the yield of soybean by 12% compared with the control (Reinbott and Blevins, 1995). Yield increases were a result of increased pod numbers on both the main stem and branches (Reinbott and Blevins, 1995). No increase in yield was noted when the treatments were applied separately. The results of these two-way interactions are of significant interest in increasing lowbush blueberry yield.

However, varying results may occur when Mg, B, and Ca are applied together. Calcium and Mg play an antagonistic role in the uptake of B in *Pinus radiata* (Teasdale and Richards, 1990). It has been noted that Mg is effective in reducing B toxicity in instances of high B soils (Teasdale and Richards, 1990). The mechanism responsible for this reduction is the same as the one that causes B deficiency in the cultured pine cells mentioned above. Research conducted by Teasdale and Richards (1990) indicated that a critical acceptor molecule had a greater affinity for Ca than for Mg and that B was not strongly bound. Magnesium competes with Ca at this acceptor site and only a small portion of the acceptor

will be boronated (Teasdale and Richards, 1990).

Improvements in experimental design and data analysis have resulted in experiments which examine the main and interactive effects of plant nutrients. Studying the nutrient interactions of three factors at five levels using a factorial design would require 125 experimental units per replicate (May and Pritts, 1993). The cost and time required to maintain such an experiment is unmanageable. The use of response surface methodology enables a reduction of the number of experimental units from 125 to 15 (May and Pritts, 1993). A three-factor, central, composite design can be used to identify the specific orthogonal treatment combinations required to obtain a second-order response surface (John, 1971), assuming no higher order interactions. Response surface methodology, an extension of the 2^K experimental design, allows a search for optimum levels of factors (Montgomery, 1997). Visual observations of a response surface plot allows one to see how responses are altered at various input levels.

The objectives of this experiment were to examine i) the main and interactive effects of B, Ca and Mg as they affect the winter hardiness, vegetative and reproductive components of the lowbush blueberries and ii) to determine if the influence of B on lowbush blueberries is enhanced or impaired by the addition of other foliar-applied nutrients.

3.2. Materials and Methods

Interactions of B, Ca and Mg on lowbush blueberry vegetative and reproductive growth were investigated in a commercial blueberry field owned by Purdy Resources at Lynn Mountain, Nova Scotia (45° 30′ N, 64° 15′ W). The field consisted of *V. angustifolium* clones in the crop phase of production during the 1998 growing season.

The levels of the factors selected were based on previous studies and commercial recommendations (Phosyn Plc, York, UK). A three-factor, rotatable, central, composite design (Cochran and Cox, 1957) was used to identify the specific orthogonal treatment combinations required to obtain a second-order response surface. Five levels of each of the three factors (B, Ca and Mg) were selected. Treatments were applied in a randomized complete block design and replicated three times as specified in Appendix I to the 4 x 8 m plots. The center point treatments (B at 350 ppm, Ca at 4000 ppm and Mg at 1000 ppm in 310 $L \cdot ha^{-1}$ of water) were included twice per replicate for a total of 48 experimental units to improve the estimate of error.

The foliar-applied B, Ca and Mg treatments were applied with a carbon dioxide (CO_2) powered sprayer (R+D Sprayers, Opelousas, La.) at 220 kPa. Two metre buffers were included both at the ends and sides of the plot to minimize the effects of overspray. Treatments were applied at tip dieback of the sprout year (August 15, 1997) and prior to full bloom of the crop year (May 27, 1998). The first treatment was applied to the whole 4 x 8 m plot. The second application was made to only half of the plot allowing the comparison of single vs. double applications.

Leaf nutrient levels were determined by taking whole-stem leaf tissue samples from

20 randomly selected plants. Samples were collected prior to leaf drop in the late summer of the sprout year, and just prior to fruit set approximately 14 days after application. Leaf tissue nutrient levels were analysed by using a dry ash procedure. Leaves were removed from 20 stems randomly selected within each plot. Leaf samples were dried at 60° C for 3 days and ground with a Wiley Mill to pass through a 20-mesh screen. After the samples had been ground, a 1 g +/- 0.0005 g sub-sample was placed in a crucible and pre-ashed for two hours using a hot plate. After pre-ashing the samples were placed in a muffle furnace (Lindberg Hevi-Duty, Watertown, WI) at 500° C for 4 hours. Samples were then digested for 1 hour in 5 mL of 1.0 HCl then transferred to falcon tubes. The total volume was adjusted to 50 mL using deionized water. The samples were centrifuged (International Equipment Company, Needham, MA) at 3000 rpm for 1 hr. Following this, the supernatant was decanted into acid-washed scintillation vials. The tissue samples were also analysed at the Prince Edward Island Department of Agriculture and Forestry Laboratory (Charlottetown, P.E.I.), using the ICAP procedure.

Whole-stem samples were collected in the early spring of the crop year (March, 19) to assess winter injury. The buds were cross-sectioned to examine the degree of oxidative browning of primary, secondary and tertiary floral primordia (Figure 3.1). The terminal, and the fourth and eighth buds from the apical bud were chosen to be examined. Floral bud injury ratings were assigned as follows: no damage = 1, damage to primary primordium = 2, damage to secondary primordium = 3, and damage to tertiary primordium = 4. A cross-section of the stem at these bud locations was also made to determine the extent of damage to the vascular system. Injury ratings to the vascular tissue were given as follows: no damage = 1, necrosis

of less than 50% of the vascular tissue = 2, necrosis of 50-90% of the vascular tissue = 3, and necrosis of greater than 90% of the vascular tissue = 4.

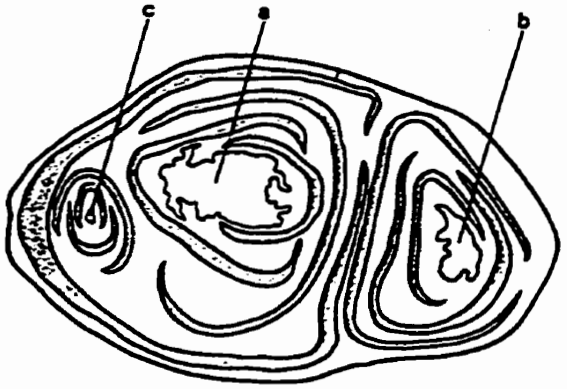

Figure 3.1. Cross-sectional diagram of a floral bud showing the (a) primary floral primordium, (b) secondary floral primordium, and (c) tertiary floral primordium. Source: Galletta and Himerlick, 1990.

Yield potential was measured at bud break (May 12) of the crop year. Twenty stems from each plot were clipped and placed in water-filled cups in the greenhouse (approximately 23°C) and flowers were allowed to emerge. The number of inflorescences, buds, nodes and stem length were measured. Stems were gathered in a similar manner after fruit set (June 29) to again observe the yield components. Data were collected on stem and floral zone lengths, number of nodes, flowering nodes, flowers, and set fruit.

Yield measurements were taken on August 20, by harvesting all fruit within a 1 m^2 quadrat. Three samples were taken from each half of the plot and were weighed using an electronic field balance (Mettler PE 6000, Burlington, ON). The mean of the three samples was used as a yield estimate. The areas were randomly selected with the restriction that any bare patches were excluded, in order to reduce variability attributed to uneven cover.

Berry samples of approximately 500 g of fresh fruit were retained to determine

individual berry weights. In the laboratory 50 g samples of berries were massed using an electronic balance (Mettler PE1600, Burlington, ON). The number of berries in each 50 g sample were counted and individual berry weights were determined.

Before regression coefficients could be derived and response surfaces calculated, the data were examined using Minitab (Minitab Inc., State College, PA) to determine whether transformation of the data was necessary to induce normality and constant variance (John, 1971). By using Proc RSREG in SAS (SAS Institute, Cary, N.C.), a second order model was fitted and the critical values that optimize leaf nutrient levels were determined (SAS Institute, 1985).

The full model used in regression analysis to calculate the response surface was:

$$\text{Response} = \text{Intercept} + B + Ca + Mg + (B \times Ca) + (B \times Mg) + (Ca \times Mg) + B^2 + Ca^2 + Mg^2 + \text{Error}$$

The individual components of the model were evaluated for their significance. If terms were found to be insignificant, they were removed (May and Pritts, 1993). The beta coefficients given by Proc RSREG were used to generate a response surface and determine the levels of the foliar sprays that optimize yield components (SAS Institute, 1985).

3.3. Results

Leaf Nutrient Levels - Autumn Application.

Leaf nutrient levels of B, Ca and Cu were significantly affected by the foliar-applied nutrient applications in the sprout year (Table 3.1). Boron concentrations in the tissue were affected by the main effect of the B application and also by the Ca×Mg interaction. The predictive equation which describes tissue B levels at various levels of nutrient applications was developed [$y = 32.78 + 3.88\ (B) + 1.74\ (Ca \times Mg)$]. Boron levels in the plots determined after application at tip-dieback of the sprout year ranged between 26.4 - 43.6 $\mu g \cdot g^{-1}$ (Table 3.2). The standard leaf levels for B in the sprout year is 24 $\mu g \cdot g^{-1}$ (Trevett *et al.*, 1968). The mean plot B values for all treatments are greater than the minimum standard. However, some were greater than the 40 ppm concentration that is considered the upper limit. Although most plots were in the range of sufficiency, a few were approaching toxicity (Trevett *et al.*, 1968).

Tissue Ca levels were affected by the main effect of Ca in the applications. A predictive equation [$y = 0.61 + 0.025\ (Ca)$] was developed to express how the leaf Ca concentration reacts to changes in Ca application rate. The mean leaf Ca levels (Table 3.2) for all plots range between 0.54 and 0.66% dry weight. These values are greater than the critical level given by Trevett *et al.* (1968) of 0.16% and at the upper end of the sufficiency range (0.40 - 0.65%) (Townsend and Hall, 1970). Changes in Cu concentration were influenced by the main effect of Ca, the square of Ca, the B×Mg interaction and by the square of B. The equation developed to predict Cu levels was [$y = 2.46 + 0.125\ (Ca) + 0.168\ (Ca^2) + 0.132\ (B \times Mg) + 0.119\ (B^2)$]. Tissue Cu levels were between 2.32 - 3.25 $\mu g \cdot g^{-1}$.

Though the levels of P, K, Mg and Zn were not affected by the autumn applications, they were generally sufficient. Tissue concentrations of P (Table 3.2) were slightly higher than the optimal range 0.08 - 0.12% (Townsend and Hall, 1970) and greater than the minimum standard as 0.08% (Trevett *et al.*, 1968). The mean leaf P concentrations ranged between 0.124 - 0.140%. Potassium concentrations (Table 3.2) were within the sufficiency range of 0.40 - 0.55% (Townsend and Hall, 1970) and were greater than the minimum standard of 0.22% (Trevett *et al.*, 1968). The leaf K levels were between 0.469 - 0.516%. The mean tissue Mg levels (Table 3.2) in all plots ranged between 0.176 and 0.212% dry weight. These levels are considered to be sufficient as most fall in the sufficiency range (0.15 - 0.20%) given by Townsend and Hall (1970) and are greater than the minimum standard (0.07%) given by Trevett *et al.* (1968). Leaf Zn levels ranged between 6.76 - 9.76 $\mu g \cdot g^{-1}$. In the sprout year Zn levels are recommended to be between 10-24 $\mu g \cdot g^{-1}$ (Trevett *et al.*, 1968), although major deficiency symptoms are not observed until levels are below 5.8 $\mu g \cdot g^{-1}$.

Leaf Nutrient Levels - Application at Bloom.

Tissue nutrient levels, sampled at fruit set approximately 14 days after application at 80% bloom (Table 3.3), were confounded due to an error in sampling. Rather than taking the tissue samples individually from the once and twice sprayed sections, samples were taken from the whole plots. The results of these findings are provided but valid conclusions cannot be drawn from these data.

Leaf B levels were between 20.0 and 29.6 $\mu g \cdot g^{-1}$ (Table 3.3). These are below the crop year standard of 30 $\mu g \cdot g^{-1}$ (Trevett *et al.*, 1968). Calcium levels ranged between 0.450 -

0.505% dry weight and were considered sufficient (Townsend and Hall, 1970; Trevett *et al.*, 1968) for the crop year. Magnesium levels in the tissue were between 0.147 - 0.183% These levels are also considered to be sufficient (Townsend and Hall, 1970; Trevett *et al.*, 1968).

The mean levels of K (0.470 - 0.527%) and Cu (4.23 - 6.60 $\mu g \cdot g^{-1}$) were considered to be within the range of sufficiency. Phosphorus levels (0.147 - 0.170 $\mu g \cdot g^{-1}$) were at the high end of the sufficiency range (Townsend and Hall, 1970; Trevett *et al.*, 1968). Zn levels were between 9.50 - 12.53 $\mu g \cdot g^{-1}$ which is at or slightly below the low end of the sufficiency range of 12-30 $\mu g \cdot g^{-1}$ (Trevett *et al.*, 1968). The levels were greater than the 7.0 $\mu g \cdot g^{-1}$ where symptoms of deficiency are pronounced (Trevett *et al.*, 1968).

The levels of P, Mg, B and Zn were all significantly affected by the treatment applications when measured during the crop year (Table 3.1).

Winter Injury.

There was no significant effect of foliar sprays applied at tip dieback in the sprout year on the fruit bud number of stems sampled prior to bud break in the cropping year (Table 3.4). The mean bud numbers per stem ranged between 5.23 and 7.40 (Table 3.5). There was a marginally significant effect of Ca on the degree of winter injury to the vascular tissue (Table 3.4). Ca was beneficial in reducing winter damage even though the degree of winter injury in 1997-1998 was minimal due to mild temperatures and sufficient snow cover (Figure 3.2). The degree of vascular damage was not correlated with the yield of once-sprayed plots. The model which expresses the relationship between winter injury and calcium is $y = 0.723 - 0.095(Ca)$.

Winter injury ratings of the terminal bud (Table 3.5) indicated that there was a marginally significant effect of B on winter injury (Table 3.4). There was a positive relationship between increased B application rates and increased severity of winter damage (Figure 3.3). As boron levels increased at various levels of Ca while Mg was at a low level, the incidence of winter injury to the terminal bud increased. The prediction equation which describes the relationship is [y = 1.475 + 0.085 (B)]. The degree of winter injury to the fourth bud was not affected by treatment applications.

Yield Components - Bud Break.

The yield components which were measured at bud break were stem length, flowers, inflorescences and flowers per inflorescence (Table 3.6). There was no effect of summer-applied foliar B, Ca, and Mg applications on the stem length. Stem lengths ranged between 17.43-22.50 cm (Table 3.6). There was also no effect on the total number of flowers per stem. Treatment means ranged between 20.9-36.4 flowers per stem.

The total inflorescences per stem ranged between 4.28 and 7.42 (Table 3.6) and was significantly affected by a B×Ca interaction [y = 12.678 - 1.569 (Ca×B), (Table 3.4)]. With B at a high level (coded values greater than 0) and Ca at a low level (coded value less than 0) or vice versa, with Mg being held constant, the number of inflorescences increased (Figure 3.4). When Ca and B were both at high levels or both at low levels, the number of inflorescences per stem decreased. The number of flowers per inflorescence was affected by the main effect of Ca [y = 5.065 + 0.243 (Ca)]. The range of flowers per inflorescence was between 4.30- 5.52. As Ca increased, the number of flowers per inflorescence increased.

Yield Components - Fruit Set.

Results for yield components that were sampled just after fruit set were also confounded due to a sampling error. There was no significant effect of treatment applications on the number of flowering nodes, number of flowers or on the floral zone length (Table 3.7). The number of nodes and set fruit, along with the overall stem length were affected by treatment applications (Table 3.7)

The number of flowering nodes per stem was between 3.45 and 6.57 (Table 3.7). The number of flowers per stem was between 11.3 and 23.0 (Table 3.7). The floral zone length for the plots was between 2.81 cm and 5.05 cm (Table 3.7). The number of nodes per stem was between 16.5 and 24.2 (Table 3.7). The stem length was between 17.18 cm and 20.42 cm (Table 3.7). The number of set fruit per stem was between 9.0 and 21.3 (Table 3.7).

Yield.

There was no significant difference between the yield of once sprayed vs. twice sprayed plots. In some treatment combinations, through visual observation, it appeared as though there were differences between once and twice sprayed halves. However, these were not detected statistically (Table 3.8). The yield of once-sprayed plots was between 328.4 and 576.4 $g \cdot m^{-2}$. The yield of twice-sprayed plots was affected by the treatment applications with the average yield of twice sprayed plots ranging from 288.6 to 677.9 $g \cdot m^{-2}$. There was no significant effect of Ca in the model and it was subsequently removed. The Mg and B^2 regression coefficients were determined to be significant. The predictive equation that was

found to describe the yield of twice-sprayed plots was [$y = 374.6 + 55.88\ (Mg) + 56.2\ (B^2)$] (Figure 3.5).

Berry Weight.

The berry weights in the plots that were once-sprayed were not significantly affected by the treatment applications with berry weights between 0.339 - 0.401 g·berry^{-1} (Table 3.9). Again there was no significant difference between once and twice sprayed plots. The berry weights of the twice-sprayed plots were affected by foliar-applied B with berry weights ranging from 0.333 and 0.439 g·berry^{-1} (Table 3.9). The predictive equation describing the relationship of B to berry weight at various levels of Mg, with Ca held at the middle level is [$y = 0.357 + 0.021\ (B^2)$] (Figure 3.6).

3.4. Discussion

Leaf Nutrient Levels.

Response surface methodology (RSM) is a very useful statistical technique for input levels which optimize a response. In this experiment, it enabled a reduction of experimental units per replicate from 125 to 15. However, using RSM to investigate leaf nutrient levels is not very useful, as the optimal tissue nutrient level is neither a maximum nor a minimum. In order for a plant to have an adequate supply of a specific nutrient, it must be present in sufficient concentrations to overcome deficiency, but in a small enough quantity so toxicity is not a concern (Marschner, 1997).

The effects due to the foliar spray applications in this study were not as great as anticipated, possibly due to the leaf nutrient levels for the seven nutrients (P, K, Ca, Mg, B, Cu and Zn) tested being present at or near sufficient quantities most plots. The owner of the commercial site being used for the study noted that the field was too vigorous, susceptible to frost, and low-yielding despite adequate fertility. There were no visible signs to indicate that there were nutritional deficiencies for any element. Since all of the essential nutrients were not tested, it is difficult to identify if other nutrients (e.g. N) were limiting factors, a limitation of most nutrient field studies. In an instance where more nutrients were at insufficient levels more noticeable responses could have been detected. However, the positive yield effects seen in twice-sprayed plots are probably a function of adding micronutrients during the pollination especially B, which is noted for improving yield despite being at an adequate level (Hanson, 1991). Chen *et al.* (1998) found that B, Ca or B + Ca increased pollen germination on the

stigmata by 8% in clones known to be B deficient. In this study Ca did not have a significant effect on yield.

When experimenting with lowbush blueberries it is necessary to be aware of the inherent variability within the wild population. Studies on B and Ca in lowbush blueberry production in the past (Smagula, 1993; Chen *et al.*, 1998) have investigated the effects of these foliar-applied nutrients at a clonal level. While this technique is useful in reducing the variability, it is not easily applicable to commercial situations without further research. It is not feasible for growers to test various clones for their nutrient levels and to make applications to clones at variable rates. In this study large areas of the field which were similar were chosen as blocks and large plots were used to increase the chance that multiple clones would be present in a plot. To accommodate for this variability, many samples were taken to improve the estimate of the actual mean. A limitation of using this technique is that there is poor reproducibility among replications. This is to be expected as there is much more variability (environmental conditions, variation within the field and genotypic differences) (May and Pritts, 1993) in field experiments than those conducted in controlled environments. Although both are suitable, it is felt that the technique used in this study is of more benefit to commercial producers.

Effectiveness of Application Method.

Foliar applications of B, Ca, and Mg are quite practical in providing developing tissues with nutrients at critical growth stages. Foliar applications are important for B and Ca in overcoming limited mobility (Gardner *et al.*, 1985) and for Mg by relieving the competition

with other cations (Marschner, 1997). Calcium and B are both easily leached in the soil and this constraint is eliminated by foliar applications. Other advantages to using foliar applications include avoiding nutrient immobilization and eliminating the problem of availability under conditions of low soil pH. Although the problem of ionic competition that occurs in root uptake of B, Ca and Mg is eliminated, competition may exist when these are taken in via the leaf (Marschner, 1997).

The greatest problem associated with using foliar-applied nutrients in lowbush blueberries during the crop year is finding a suitable application method at a commercial level. Variable results have been noted among producers when applications were made at low water volumes or using an air-blast (mist blower) sprayer. Due to the nature of the pump which pulsates, applications tend to be uneven. Foliar applications using a boom sprayer result in excess tracking in the field subsequently reducing yield. Aerial applications are likely too expensive to be practical, thus growers must use larger water volumes and make improvements to equipment. Further research examining these factors and the feasibility of applying foliar nutrients tank-mixed with fungicides, used to prevent blight, is necessary.

Winter Hardiness.

The effects of the foliar-applied nutrients on the winter hardiness of the lowbush blueberry were variable. The damage to the terminal bud was increased when boron was at a high level conflicts with results in highbush (Blevins *et al.*, 1996). Boron forms a cell wall complex that is quite flexible. This results in a cell wall that would be able to handle freeze-thaw incidences more aptly that a less flexible structure. In Nova Scotia, the 1997-98 winter

was very mild with adequate snow cover to provide an insulating layer to the overwintering plants. The effectiveness of B in reducing winter injury may have been masked. Winter injury, typically a concern of growers, was not a severe problem during this particular year.

Yield Components.

The yield components that were affected by autumn applications of foliar-nutrients were the number of inflorescences per stem and the number of flowers per inflorescence. Smagula (1993) found the increase in the number of flowers per bud was attributed to B. Chen *et al.*, (1998) found a decrease in the number of flowers per bud when Ca was applied solely compared with the control. This decrease did not occur when B was applied alone or when B and Ca were applied together. In all but one of the treatment combinations used, B and Ca were applied together and a positive effect of calcium was noted.

The number of inflorescences responded variably at different levels of B and Ca. When both were present at high or low levels the number of inflorescences decreased. This indicates that there was an important interactive effect where one nutrient was required at a high level and the other was at a low level. The fact that either combination can increase the number of inflorescences indicates that there may be more than one optimal level. These findings concur with those of May and Pritts (1993) who suggest that because yield components respond differently to nutrient applications, more than one optimal level may exist. This indicates the complexity involved in understanding nutrient interactions in field experiments.

Yield.

In comparing the yield of once vs. twice sprayed crops, no significant difference was found, though the average plot yield in twice-sprayed plots was greater (Table 3.8). Yield increases in twice-sprayed plots could be attributed to more product being applied, though it is more likely due to splitting nutrient applications. Supplying nutrients at critical stages of growth is key in maximizing yields. It is especially important at flowering since root activity decreases during the reproductive stage resulting in reduced nutrient uptake (Marschner, 1997). In soybean production, multiple foliar applications of B+Mg produced the greatest yields (Reinbott and Blevins, 1995). The economic feasibility of split nutrient applications in lowbush blueberries requires further examination before being adopted as a management practice.

The greatest yields in twice-sprayed plots were achieved when B was at a high level and Mg at a low level or vice versa (Figure 3.4). In soybeans, foliar applications of B and Mg individually did not increase yield. However, when applied together, yield increases attributed to increased pod numbers were noted. These results do not necessarily contradict the findings of this study as both B and Mg were present in the treatment applications and the levels that maximized yield were determined. These occurred at two different concentrations of B and Mg. It appears that the levels theorized near the optimum are not sufficiently high enough to maximize the yield response (Figure 3.4). Further exploration beyond the upper concentrations used in this experiment may locate the optimal level for maximum production.

Calcium has had contradictory effects on yield when applied in conjunction with B. Cranberry yields were increased, due to improved fruit set, by split B+Ca applications made

prior to flowering and at full bloom (De Moranville and Deubert, 1987). However, in a lowbush blueberry study there was no difference in yield due to autumn foliar applications of B+Ca compared with the control (Chen *et al.*, 1998). Foliar applications of Ca actually decreased yield compared with the control (Chen *et al.*, 1998). This study concurs with Chen's (1998) findings as there was no effect of B+Ca on yield. Perhaps the form of Ca applied was not assimilated, or, Ca at reproductive stages is not as critical as B and/or Mg in the lowbush blueberry. The Ca concentration used may have been insufficient. Indications are that higher levels of Ca may be necessary to produce a response.

Berry Size.

Increases in yield associated with B + Ca and B + Mg applications have generally been attributed to increased berry or pod number (De Moranville and Deubert, 1987; Reinbott and Blevins, 1995). In this study, yield was influenced by the effect of B and Mg. B was the only nutrient that had a significant effect on berry weight. Yield increases in twice sprayed plots were mostly a result of increased berry weight (Figure 3.6). The similarity of the response surfaces confirm the positive correlation for yield (Figure 3.5) and berry weight (Figure 3.6). Chen *et al.* (1998) suggest that B applications increased the number of seeds per berry due to improved pollen germination. Boron supplied at flowering had a positive effect on pollen tube growth resulting in yield effects in twice sprayed plots that were not present in plots that received B only during the sprout year (Table 3.8).

3.5. Conclusions and Summary

Tissue samples taken after application in the sprout year indicated that the nutrient levels (P, K, Ca, Mg, B, Zn and Cu) were in the range of sufficiency. In some cases (B and P) the upper limit of the sufficiency range was met and surpassed, though not by greater than 10%. Winter injury to the vascular tissue was marginally decreased by Ca, and damage to the terminal bud was marginally increased by B application, though neither was strongly correlated with yield. Yield components were altered as a result of applications,but the effect did not appear to be consistent. There was no significant difference in berry size, and yield between plots that were once-sprayed vs. those that were twice sprayed. Yield and berry size in the once-sprayed plots were not significantly affected by the foliar-applications. In twice-sprayed plots the effect of Ca was not significant and was removed from the model. Yield in twice sprayed plots was significantly affected by the B and Mg. Yield increases occurred when B was at a high level and magnesium at a low level or vice-versa. There was positive correlation between berry weight and yield in twice sprayed plots.

Though nutrient levels were found to be adequate in both the sprout and crop years, yield increases were noted in twice sprayed plots when applications were made at full bloom. This indicates that although nutrients may be present at a sufficient level there may be deficiencies in meristematic regions. This is of most concern when there is limited redistribution of nutrients (i.e., B and Ca) from sources to developing sinks. At particular stages of growth, nutrient uptake via the roots may be reduced due to competition for photoassimilates. Consequently, foliar nutrient applications are the best method to provide adequate nutrition to reproductive tissues.

The heterogeneity of lowbush blueberry populations provide a challenge to researchers. It is difficult to ensure that all blocks are similar. Individual clones used as replicates reduces the inherent variability but it requires adaptation to apply this to commercial situations. Using large plots with diverse populations simulates field conditions, though many samples must be taken to get a mean representative of the population. Increasing the number of replications would improve the precision by increasing the number of error degrees of freedom.

Maximum yields occurred at high levels of B or Mg when the other was at a low level. As maximums were not achieved exploration beyond the range used in this study may produce greater yield increases. Ca had no effect on yield suggesting that perhaps the range used was not sufficiently close to the optimum to elicit a response. Further research of the influence of foliar-applied Ca at a higher range of concentrations on the lowbush blueberry provide insight on its usefulness.

Increased berry size was the yield component most responsible for the differences in yield in twice sprayed plots. The nutrient that was responsible in increasing berry weight was B. This provides further evidence that providing B to developing lowbush blueberry flowers may be pivotal in improving production efficiency. The impact of foliar nutrient applications may be most significant during poor pollination seasons. Studying the influence of biotic and abiotic factors on foliar nutrient supplementation is central in gaining a greater understanding of this management practice.

Table 3.1. Leaf nutrient levels of lowbush blueberry leaves in the sprout (1997) and crop (1998) phases of production with significant regression coefficients as influenced by foliar applications[z] of B, Ca, and Mg at Lynn Mountain, N.S. in 1998.

	Significant regression coefficients [x]	
Nutrient[y]	September 1997	June 1998
Phosphorus	None	0.0041(B)**
Potassium	None	None
Calcium	0.0246(Ca)**	None
Magnesium	None	0.0093 (B^2)**
Boron	3.880(B)***, 1.744(Ca×Mg)*	1.6498(B)***, 1.7885(B^2)***, 1.1987(Ca^2)**, 1.1280(Mg^2)**
Copper	0.1251(Ca)**, 0.1675Ca^2)***, 0.1322(B×Mg)*, 0.1186(B^2)*	None
Zinc	None	-0.006918(B×C)*

[z] Foliar B, Ca and Mg were applied at tip dieback (sprout phase) and prior to bloom (crop phase) as specified by the central composite design.

[y] Tissue samples, comprised of foliage from 20 stems·plot^{-1}, were taken approximately 14 days after application.

[x] Data were analysed using response surface methodology to determine significant regression coefficients, if any, for each parameter. Significant regression coefficients at P< (0.10, 0.05, and 0.01) are indicated by (*,**,***), respectively.

Table 3.2. Treatment combinations of B, Ca, and Mg as specified by the central, composite design and corresponding lowbush blueberry leaf nutrient levels of P, K, Ca, Mg, B, Cu, and Zn at Lynn Mountain, N.S. prior to leaf drop in 1997.

Treatment [z]				Nutrient content [y]						
				% dry weight				($\mu g \cdot g^{-1}$)		
#	B (ppm)	Ca (ppm)	Mg (ppm)	P	K	Ca	Mg	B	Cu	Zn
1	142	1622	405	0.130	0.476	0.568	0.193	32.6	2.81	7.36
2	558	1622	405	0.135	0.480	0.540	0.178	39.0	2.55	6.76
3	142	6378	405	0.134	0.507	0.550	0.176	31.5	2.82	7.85
4	558	6378	405	0.134	0.511	0.626	0.190	37.9	2.90	8.71
5	142	1622	1595	0.124	0.469	0.573	0.204	26.4	2.35	9.76
6	558	1622	1595	0.130	0.516	0.600	0.202	37.8	2.69	8.33
7	142	6378	1595	0.128	0.499	0.646	0.212	32.5	2.72	9.34
8	558	6378	1595	0.140	0.510	0.628	0.197	43.6	3.25	8.46
9	0	4000	1000	0.133	0.493	0.585	0.208	32.7	2.86	8.40
10	700	4000	1000	0.134	0.510	0.622	0.206	43.2	2.74	8.19
11	350	0	1000	0.126	0.489	0.562	0.190	37.9	2.82	9.33
12	350	8000	1000	0.133	0.494	0.660	0.199	35.9	3.06	8.58
13	350	4000	0	0.126	0.477	0.646	0.186	38.0	2.51	7.62
14	350	4000	2000	0.133	0.499	0.627	0.189	38.0	2.52	7.64
15	350	4000	1000	0.128	0.500	0.631	0.185	36.1	2.32	7.79
16	350	4000	1000	0.131	0.513	0.616	0.192	29.0	2.60	7.90

[z] Foliar B, Ca and Mg were applied at tip dieback (sprout phase) as specified by the central composite design.
[y] Tissue samples, comprised of foliage from 20 stems·plot^{-1}, were taken approximately 14 days after application.

Table 3.3. Lowbush blueberry leaf nutrient levels of P, K, Ca, Mg, B, Cu, and Zn as influenced by foliar-applied B, Ca, and Mg at Lynn Mountain, N.S. at fruit set in 1998.

	Nutrient content[y]						
	% dry weight				($\mu g \cdot g^{-1}$)		
Treatment #[z]	P	K	Ca	Mg	B	Cu	Zn
1	0.153	0.493	0.467	0.170	23.8	4.73	10.70
2	0.160	0.527	0.500	0.177	29.6	5.80	9.96
3	0.160	0.493	0.463	0.160	23.8	4.90	10.30
4	0.160	0.500	0.500	0.167	27.1	4.40	11.80
5	0.147	0.493	0.463	0.173	21.9	4.30	12.53
6	0.160	0.503	0.500	0.163	25.6	4.23	10.87
7	0.155	0.490	0.505	0.180	23.9	4.90	12.05
8	0.160	0.487	0.503	0.167	27.2	4.93	12.30
9	0.150	0.500	0.480	0.175	24.8	5.55	9.50
10	0.170	0.497	0.497	0.183	28.5	6.23	11.90
11	0.153	0.480	0.477	0.157	25.4	4.87	11.50
12	0.157	0.473	0.457	0.170	24.2	4.90	11.00
13	0.150	0.483	0.483	0.173	24.8	4.87	11.70
14	0.160	0.510	0.493	0.153	24.3	6.13	11.50
15	0.163	0.523	0.453	0.147	22.6	4.70	10.40
16	0.153	0.470	0.450	0.160	20.0	6.60	11.33

[z] Foliar B, Ca and Mg were applied at tip dieback (sprout phase) and prior to bloom (crop phase) as specified by the central composite design.

[y] Tissue samples, comprised of foliage from 20 stems·plot^{-1}, were taken approximately 14 days after application.

Table 3.4. Reproductive yield components, vegetative growth and winter injury of lowbush blueberries and significant regression coefficients as influenced by foliar-applied[z] B, Ca, and Mg at Lynn Mountain, N.S. in the 1998 cropping season.

Parameter	Regression coefficients[y]
Yield (1)	None
Yield (2)	55.88(Mg)*, 56.20(B^2)*
Berry Wt (1)	None
Berry Wt (2)	0.021485(B^2)*
Stem length (Bud)	None
Total inflorescences	-1.569(B×Ca)**
Total flowers	None
Flowers/inflorescence	0.24297(Ca)**
Nodes	15936(Ca^2)*, -85658(Ca×Mg)*
Flowering nodes	None
Stem length	0.6798(B×Ca)*, -0.8044(B×Mg)**
Floral zone length	None
Flowers	None
Fruit set	-1.89(B^2)*, -2.406(Ca^2)**
Fruit bud number (winter)	None
Vascular damage (winter)	-0.09468(Ca)*
Terminal bud damage (winter)	0.08456(B)*
Bud damage 4th bud (winter)	None

[z] Foliar B, Ca and Mg were applied at tip dieback (sprout phase) and prior to bloom (crop phase) as specified by the central composite design.

[y] Data were analysed using response surface methodology to determine significant regression coefficients, if any, for each parameter. Significant regression coefficients at P< (0.10, 0.05, and 0.01) are indicated by (*,**,***), respectively.

Table 3.5. Influence of foliar-applied B, Ca, and Mg on bud number and winter injury of the terminal bud, fourth bud and vascular tissue at the terminal prior to bud break in early spring of the crop phase of production at Lynn Mountain, N.S. in 1998.

Treatment #[z]	Buds per stem[y]	Winter Injury		
		Vascular tissue [x]	Terminal bud	Fourth bud
1	5.23	1.33	1.65	1.30
2	5.52	1.37	1.59	1.31
3	5.95	1.16	1.32	1.30
4	5.46	1.23	1.81	1.22
5	6.58	1.18	1.53	1.25
6	6.97	1.08	1.77	1.37
7	5.42	1.40	1.46	1.29
8	6.98	1.47	1.65	1.23
9	6.22	1.09	1.39	1.21
10	6.52	1.55	1.57	1.32
11	5.73	1.00	1.64	1.31
12	6.76	1.44	1.59	1.15
13	6.03	1.08	1.52	1.23
14	6.83	1.01	1.36	1.39
15	6.17	1.10	1.60	1.38
16	7.40	1.31	1.34	1.27

[z] Foliar B, Ca and Mg were applied at tip dieback (sprout phase) as specified by the central composite design.
[y] Values are the mean of 20 stems sampled prior to bud break in the crop phase of production.
[x] Winter injury was rated on a scale of 1-4, with 1 being no damage and 4 being complete necrosis of tissue.

Table 3.6. Influence of foliar-applied B, Ca, and Mg on the vegetative growth and reproductive yield components of lowbush blueberries prior to bloom of the crop phase of production at Lynn Mountain, NS in 1998.

	Vegetative growth and reproductive components			
Treatment #[z]	Stem length [y] (cm)	Flowers per stem	Inflorescences per stem	Flowers per inflorescence
1	18.50	20.9	4.28	4.85
2	17.50	34.4	6.98	4.83
3	18.55	35.9	6.92	5.05
4	20.08	29.1	5.50	5.52
5	19.96	28.9	5.68	4.97
6	20.41	30.6	7.18	4.45
7	20.83	33.9	6.02	5.25
8	22.50	36.4	6.68	5.22
9	20.81	33.0	6.68	4.92
10	17.43	27.8	5.13	5.15
11	18.55	29.3	7.37	4.30
12	19.03	31.4	6.12	5.13
13	19.26	30.7	6.18	4.80
14	18.33	33.6	6.38	5.23
15	21.01	38.7	7.42	5.46
16	18.69	28.6	6.47	4.57

[z] Foliar B, Ca and Mg were applied at tip dieback (sprout phase) as specified by the central composite design.
[y] Values are the mean of 20 stems sampled following bud break in the crop phase of production.

Table 3.7. Influence of foliar-applied B, Ca and Mg on the vegetative growth and reproductive components of lowbush blueberries following fruit set at Lynn Mountain, NS in 1998.

Treatment #[z]	Vegetative and Reproductive Components					
	Nodes per stem[y]	Fruit set per stem	Stem length (cm)	Floral zone length (cm)	Flowers per stem	Flowering nodes per stem
1	21.7	12.0	18.65	3.28	13.6	4.03
2	22.1	15.0	17.44	3.29	16.0	4.70
3	20.3	11.5	17.25	2.98	15.1	4.18
4	23.2	9.0	19.95	2.91	11.3	3.45
5	23.4	15.8	20.42	3.22	18.8	4.65
6	22.3	13.6	17.18	3.38	17.0	4.43
7	20.9	15.5	19.23	3.74	17.9	4.90
8	18.4	14.0	17.53	3.44	16.2	4.80
9	19.8	13.2	18.45	3.38	16.5	4.58
10	23.0	17.0	18.21	3.39	18.2	5.33
11	16.5	12.6	17.22	3.98	17.7	5.12
12	22.3	14.7	19.10	3.21	18.4	4.40
13	24.0	19.5	19.45	4.92	22.8	6.13
14	23.2	21.0	18.00	4.03	22.7	5.60
15	24.2	21.3	20.13	5.05	23.0	6.57
16	21.7	16.1	17.73	2.81	20.5	4.00

[z] Foliar B, Ca and Mg were applied at tip dieback (sprout phase) and bloom (crop phase) as specified by the central composite design.

[y] Values are the mean of 20 stems sampled following fruit set in the crop phase of production.

Table 3.8. Comparison of the influence of foliar-applied B, Ca, and Mg on the yield of lowbush blueberries in once-sprayed with twice-sprayed plots at Lynn Mountain, NS, during the 1998 cropping season.

	Yield ($g \cdot m^{-2}$)	
Treatment #[z]	Once sprayed [y]	Twice sprayed
1	328.4	337.3
2	533.1	413.8
3	386.8	288.6
4	480.2	387.6
5	396.8	651.6
6	418.6	414.9
7	576.4	517.5
8	477.8	469.9
9	335.5	476.5
10	424.2	677.9
11	469.0	344.0
12	349.8	406.9
13	456.0	477.4
14	528.5	558.5
15	386.1	349.6
16	464.1	492.4

[z] Foliar B, Ca and Mg were applied at tip dieback (sprout phase) and bloom (crop phase) as specified by the central composite design.

[y] Values are the mean of 3 - 1 m^2 subsamples taken from each plot at harvest, August 20, 1998.

Table 3.9. Comparison of the influence of foliar-applied B, Ca and Mg on the individual berry weight of lowbush blueberries in once-sprayed with twice-sprayed plots at Lynn Mountain, NS, during the 1998 cropping season.

	Individual berry weight (g)	
Treatment #[z]	Once sprayed [y]	Twice sprayed
1	0.353	0.369
2	0.394	0.337
3	0.349	0.350
4	0.354	0.398
5	0.339	0.388
6	0.364	0.393
7	0.401	0.378
8	0.391	0.333
9	0.350	0.439
10	0.345	0.426
11	0.365	0.363
12	0.348	0.351
13	0.369	0.358
14	0.396	0.428
15	0.377	0.360
16	0.354	0.336

[z] Foliar B, Ca and Mg were applied at tip dieback (sprout phase) and bloom (crop phase) as specified by the central composite design.

[y] Individual berry weights were determined by massing 50 berries from each plot and determining the average mass.

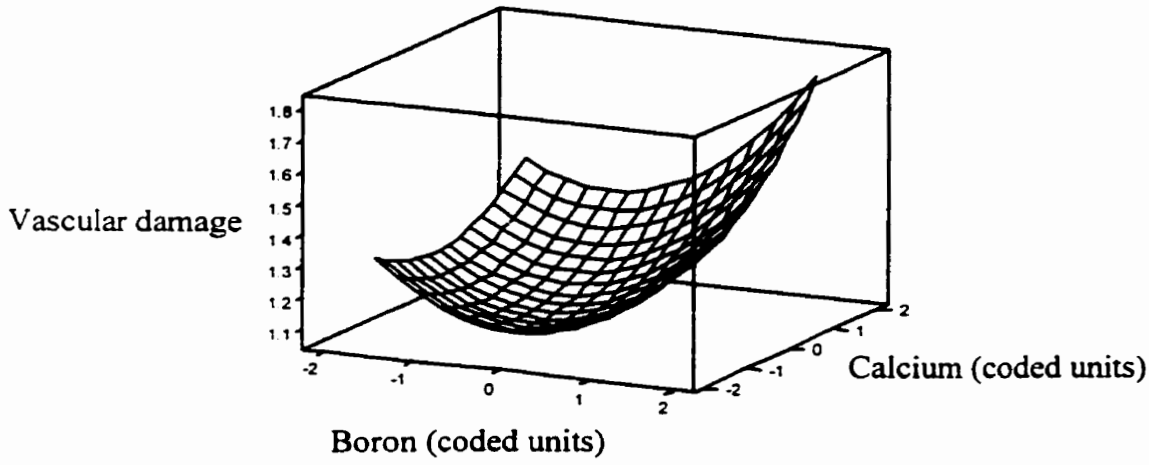

Figure 3.2. Response surface of vascular damage at the terminal bud of lowbush blueberries as influenced by foliar-applied B (coded units) and Ca (coded units) at Lynn Mountain, N.S. in 1998. Magnesium is held at a middle level (coded value=0, 1000ppm).

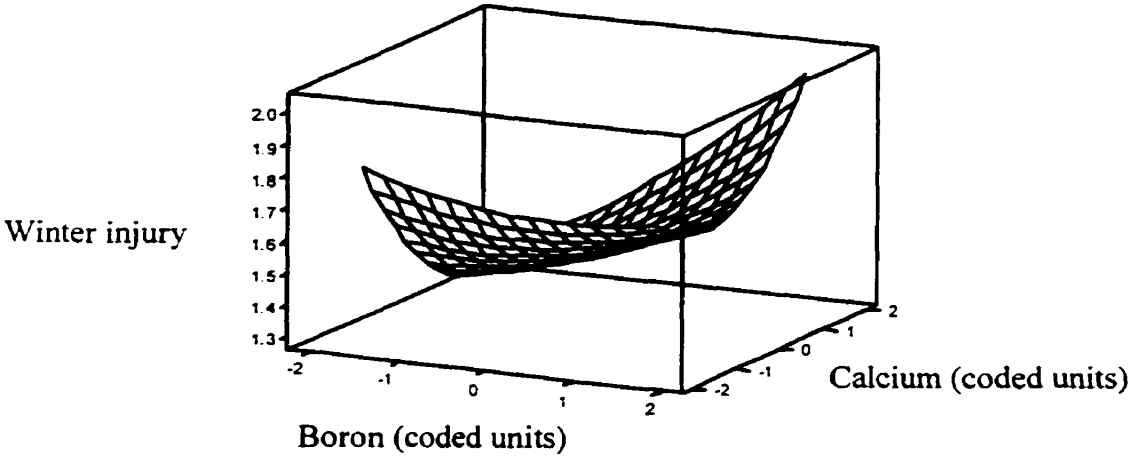

Figure 3.3. Response surface of winter injury to the primordial tissue of the terminal bud of lowbush blueberries as influenced by foliar-applied B (coded units) and Ca (coded units) at Lynn Mountain, N.S. in 1998. Magnesium is held at a middle level (coded value=0,1000ppm).

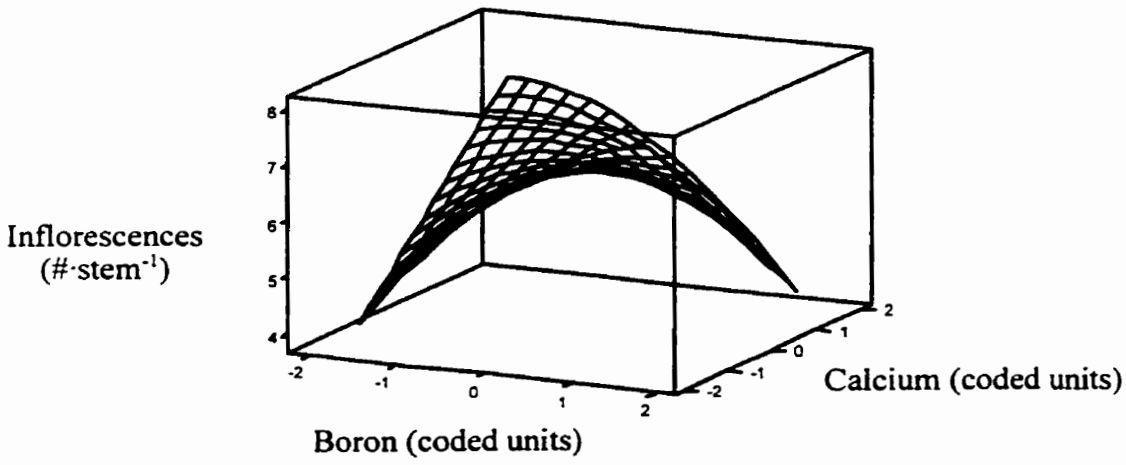

Figure 3.4. Response surface of the number of inflorescences per stem as influenced by foliar-applied B (coded units) and Ca (coded units) at Lynn Mountain, N.S. in 1998. Magnesium is held at a middle level (coded value=0,1000ppm).

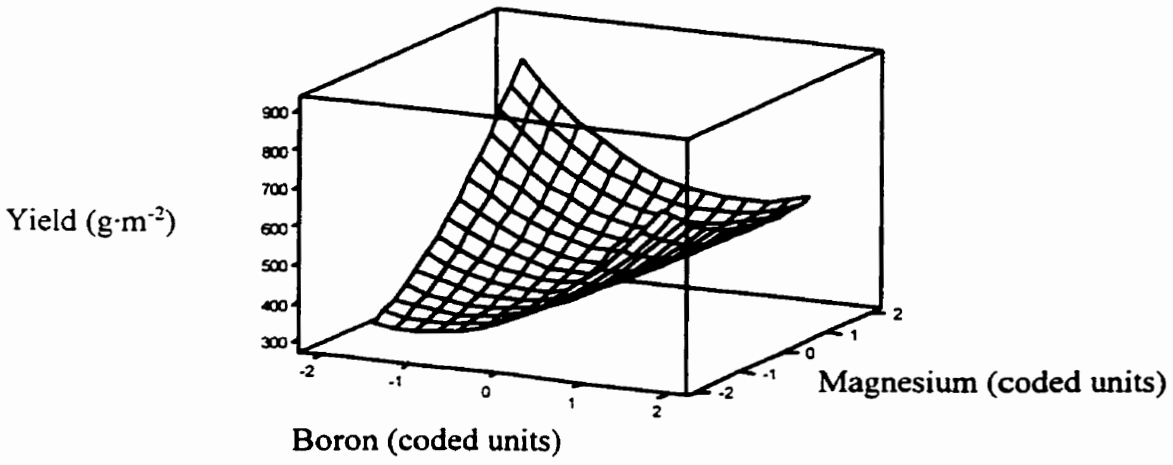

Figure 3.5. Response surface of yield in twice-sprayed plots as influenced by foliar-applied B (coded units) and Mg (coded units) at Lynn Mountain, N.S. in 1998. Calcium is held at a middle level (coded value=0, 4000ppm).

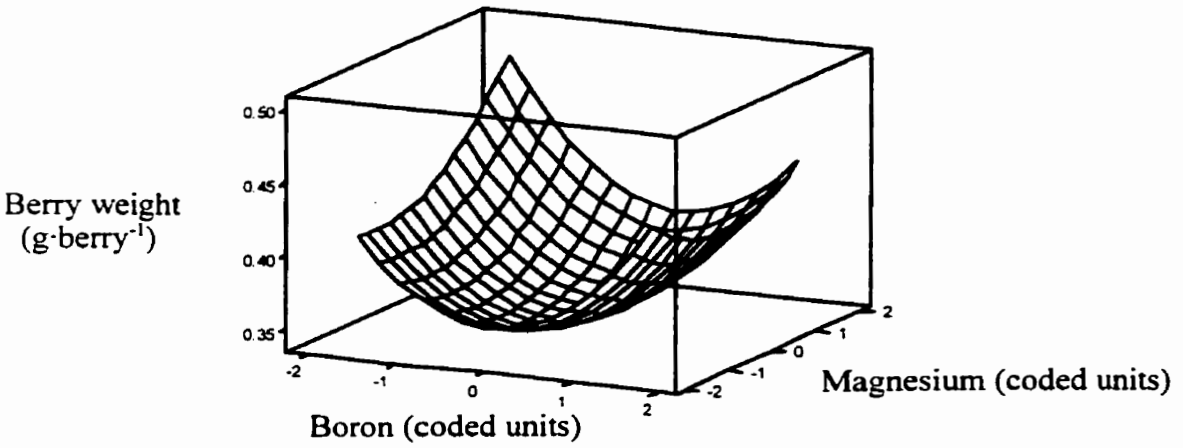

Figure 3.6. Response surface of individual berry weight in twice-sprayed plots as influenced by foliar-applied B (coded units) and Mg (coded units) at Lynn Mountain, N.S. in 1998. Calcium is held at a middle level (coded value=0, 4000ppm).

CHAPTER 4 - General Results, Discussion and Conclusions.

In lowbush blueberry research, the bulk of the mineral nutrition work has focussed on the macronutrients N, P, and K (Smagula and Hepler, 1978; Eaton and Patriquin, 1988). The roles of other macronutrients (Ca and Mg) and the micronutrients have not been investigated as extensively, even though they are important for specific physiological processes. Boron is an essential micronutrient, playing a key role in a number of physiological processes (Shelp *et al.*, 1995). Recent research in many horticultural crops has indicated that B applications, especially those foliarly-applied, hold great promise in reducing winter injury (Blevins *et al*, 1996), increasing fruit set (Hanson, 1991; Shrestha *et al.*, 1987), and subsequently increasing yield (Schon and Blevins 1987; DeMoranville and Deubert, 1987). Boron is required in greater quantity for reproductive processes than for vegetative growth (Piland *et al.*, 1944). Boron has limited phloem mobility in most plants (Gupta, 1991) and is not easily redistributed from older leaves to developing meristematic regions where demand is the greatest. Therefore, nutrients delivered directly to developing tissues via foliar applications should alleviate these constraints.

Boron deficiencies are quite common in lowbush blueberry fields (Smagula, 1993), and are generally associated with low availability in the soil (Gupta, 1979) or poor phloem mobility once B is assimilated by the plant (Gupta, 1991). Applications of B to the developing meristematic regions have increased yield of tree fruit crops when levels were both deficient and toxic (Hanson and Breen, 1985). This indicates that ensuring the B requirement of developing tissues is met is more important than the overall B status of the plant. Further

compounding this problem is that the effect of a single nutrient may be influenced by the status of others. Interactive effects occur most often when the concentration of nutrients are nearing deficiency or toxicity levels (Marschner, 1997). Rectifying these problems will lead to increased yield potential and improved production efficiency for the lowbush blueberry industry.

In Chapter two, two studies were conducted to examine the optimum method of B application and then to determine the optimum frequency and timing of application. The objective of the experiment comparing soil-applied B vs. foliar-applied B was to observe changes in B concentration in the soil and leaf tissue throughout the growing season. Also, it was anticipated that this study would provide further evidence as to whether there was an active component to B uptake and whether it was redistributed as needed by developing tissues via the phloem. The second study conducted in Chapter two investigated the optimum frequency and timing of application. Three growth stages (terminal dieback-sprout year, bloom-crop year and fruit set-crop year) considered to be critical to the development of the lowbush blueberry were selected. Applications were made at each of these times and in all possible combinations to determine if frequency of application played a role.

The study conducted in Chapter three investigated the main and interactive effects of B, Ca, and Mg on winter hardiness, yield components and actual yield of lowbush blueberries. Boron and Ca or B and Mg have been shown to promote yields of other crops when applied in combination with each other. However, when all three were applied together to the growth medium of *Pinus radiata* cultures interesting results occurred (Teasdale and Richards, 1990).

The comparison of soil vs. foliar-applied treatments in Chapter two enabled the

determination of the optimum method for improving B status in lowbush blueberries. As anticipated, the soil B level was influenced by the granular B fertilizer, while the foliar-applied treatments showed no effect. Though the soil B levels were increased, this increase did not occur until the three days after application. This lag was due to the lack of rainfall necessary to dissolve the granules into the soil. Thirty-one days after soil application the soil B levels were observed to decline. This was most likely attributed to leaching, though plant uptake could also be responsible for a portion of the decline. Therefore, results from this experiment support prior research that indicate that using soil-applied B during the cropping season include 1) the lag between application and uptake, and 2) the problem of leaching that occurs especially on sandy soils (Gupta, 1985). Furthermore, in using soil applications it is not certain that B is being supplied to the meristematic regions. These problems associated with soil-applied B minimize the potential of using it as a component of a nutrient management program in lowbush blueberry production.

The soil-applied B treatments also had a significant influence on leaf tissue B levels with levels 456% (93.8 $\mu g \cdot g^{-1}$) greater than those receiving no application; substantially above the upper standard of 40 $\mu g \cdot g^{-1}$ recommended by Trevett *et al.*, (1968). The effect of soil-applied B was not significant until 7 days after application, providing further evidence that soil applications are taken into the plant slowly making it difficult to control the amount as well as how quickly it is absorbed.

The foliar-applied B treatments, though non-significant, increased leaf B levels by approximately 20% (4.3 $\mu g \cdot g^{-1}$) compared with the control throughout the study. These differences were noted after the first day after application. However, these applications did

not increase levels above the minimum standard of 30 $\mu g \cdot g^{-1}$ in the crop year (Trevett *et al.*, 1968). Consequently, the treatment concentrations used in this study were not sufficient to increase leaf B levels to the optimal range.

Pollen germination and pollen tube growth are important physiological processes which are short lived (Wood, 1962) and are affected by B deficiency (Jenkin *et al.*, 1993). Boron is more critical in reproductive organs, and seed formation than in vegetative growth (Marschner, 1997), thus application at flower bud development and flowering are most beneficial. The results of this study concur with previous studies that concluded some horticultural crops assimilate B quickly and efficiently (Hanson and Breen, 1985), providing valuable insight into the potential of using foliar-applied B fertilizers as a nutrient source.

The yield in this study was negatively influenced by the soil-applied B treatment. The yield in plots receiving the soil-applied treatment was 19% less than untreated plots. Leaf tissue results from the soil-applied B treatments indicated that the results were due to B toxicity, and subsequently, that the rate used was too high in this particular setting. The plots receiving only foliar-applied treatments yielded 9% greater than the control. This indicated that improving the B status compared with the control may increase yield even though levels are still considered to be deficient. This supports the findings of Hanson (1991) who concluded yield increases resulted from foliar B applications even when tissue levels are deemed to be either deficient or toxic.

This research confirmed the hypothesis that foliar-applied B would be taken into the plant more quickly, efficiently, and pose less environmental concerns (i.e., leaching) than soil-applied treatments. The practical implications allow growers, after testing the B status of the

field at tip dieback during the sprout year, to make applications to improve B levels in the cropping season. This allows for remediation of sub-standard B levels and for the potential improvement of fruit set which occurs in some crops when applied at flowering. However, the findings of this study lead to the need for further research examining the best application rate and formulation of foliar-applied B and the allocation dynamics of B in the lowbush blueberry.

The first study in Chapter two confirmed that there is much promise in the use of foliar-applied B in blueberry production. Once this was determined, it is now necessary to find the optimum frequency and timing of application required. Boron applications at important growth stages in other crops have led to improved hardiness and reduced winter injury (Blevins *et al*, 1996), improved fruit set, and increased yield (DeMoranville and Deubert, 1987; Hanson, 1991; Schon and Blevins, 1987). Foliar B applications at concentrations of 300 ppm in 310 $L \cdot ha^{-1}$ were applied at either i) terminal dieback (sprout year), ii) bloom (crop year), and iii) fruit set (crop year) or at combinations of these times. To determine the optimum frequency and time of application, the leaf nutrient levels, vegetative growth, yield components, yield, and fruit size were measured.

The leaf nutrient analysis indicated the foliar-applied B treatments during the sprout year were not effective in increasing the B status in leaf tissue plants prior to winter. There was no significant difference in B levels of floral buds sampled the following spring. Since B is an important component of the cell wall (Mengel and Kirkby, 1987), plants sufficient with B have cell walls that are both fine and flexible making them less susceptible to winter injury (Pilbeam and Kirkby, 1983). The winter of 1997-98 was quite mild with good snow cover on

most fields in Nova Scotia and Prince Edward Island reducing the typical concern of winter injury. Thus, beneficial effects of B applications might have been more pronounced if more harsh environmental conditions were encountered during winter.

Leaf tissue analysis after foliar B applications in the crop year indicated that the B status of the plants was improved in treated plots. Applications prior to bloom (just after bud break) resulted in increased levels at Wood Islands, P.E.I. The application prior to fruit set resulted in the increased B levels in some cases to levels greater than the upper limit of 40 $\mu g \cdot g^{-1}$ (Trevett, 1972), though no signs of toxicity were noted. This application did not improve the yield or any of its components, though vegetative growth was increased. Perhaps this yield decrease was caused by a shift in the allocation of carbon to vegetative growth rather than for fruit production. Therefore, foliar B applications at this growth stage are not a recommended management practice.

Yield data collected at the two sites was non-significant when analysed individually. However, the models at both sites were approaching significance. When the data were combined for both sites there were significant differences. At both sites and in the combined analysis the treatment at the SY+, BC+, FC- was the highest yielding combination. The yield was 15% greater at Benvie Hill and 16% greater at Wood Islands.

The nutrient requirements of plants vary as plants enter various stages of growth and development (Marschner, 1997). Therefore, seasonal variations in the optimal concentration of foliar-applied B required are expected. A concentration considered to be adequate at a particular growth stage may not be sufficient to evoke a response at another phase of development. These considerations suggest yield increases were due to split applications (93

g of $B \cdot ha^{-1}$ at each time), providing B to the plant at critical growth stages, rather than supplying the plant with a total of 186 g of $B \cdot ha^{-1}$ as it entered the flowering stage. This could be proven by a comparison of a split application (93g of $B \cdot ha^{-1}$) versus the doubled rate (186 g of $B \cdot ha^{-1}$) applied solely in the autumn or spring. Though several split-applications of varying concentrations would result in the greatest yields and would eliminate the problem of B mobility, it would not be economically feasible. A study investigating various concentrations at the two growth stages (tip die-back - sprout year, prior to bloom - crop year) would be beneficial in determining the optimal concentrations to use at each time. In the absence of toxicity concerns, the most economical outcome for producers would be increasing the rate and applying at only one of the times, thus reducing the cost of production. Producing the same or slightly decreased yields with a higher rate at one growth stage would result in similar economic returns.

Determining the optimum application rate of mineral nutrients is complicated by nutrient interactions (May and Pritts, 1993). The level of one nutrient can influence the effect of another, especially when levels are near deficiency or toxicity (Marschner, 1997). The study conducted in Chapter three examined the effects of two other foliar-applied nutrients (Ca and Mg) with foliar-applied B in lowbush blueberries. This study helped evaluate whether Ca and Mg foliar applications would enhance or interfere with B applications.

The technique of response surface methodology (RSM) used in analysing the data for Chapter three has not been used extensively in horticultural field studies. However, it has advantages compared with conventional factorial designs (Montgomery, 1997). To investigate the effects of three factors at five levels using RSM, the number of experimental units per

replicate can be reduced to one-eighth of that required for a factorial experiment (May and Pritts, 1993). Response surface methodology is an excellent technique to use when the optimal level of the response variable is a maximum or a minimum (i.e., yield, fruit set). The leaf tissue samples taken in Chapter three were analysed using this method. In plant nutrition the optimum tissue concentration of a nutrient is neither a maximum nor a minimum as deficiency or toxicity would occur. In most cases the coefficients determined by this study are useful since the maximum values attained are generally within the range of sufficiency. If the maxima and minima were outside the range of sufficiency then the usefulness of the coefficients would be questionable. This study illustrates how this statistical technique can be quite useful in horticultural studies in reducing the time and resources allocated to the experimentation.

Using RSM in a nutrient interaction study may locate more than one level of the settings that maximizes yield (May and Pritts, 1993). This was the case with the yield in Chapter three (Figure 3.4) which was maximized at both high levels of B and low levels of Mg and at high levels of Mg and low levels of B. Either application combination would maximize yield and be a suitable alternative. In soybean, B foliarly-applied with Mg resulted in increased yield due to increased pod numbers (Schon and Blevins, 1987). This demonstrates the effects nutrient interactions play in complicating nutrient management programs.

During the sprouting (1997) and cropping (1998) years, the summers were quite dry in Atlantic Canada. Meteorological conditions have often been cited as cause for yield fluctuations, though no significant correlation has been found between yield and weather conditions (Hall *et al.*, 1982). In 1998, yields were below average in several areas in Nova

Scotia, with lack of moisture in the sprout (1997) and crop (1998) years being the cause (McIsaac, personal communication). Boron uptake from the soil is generally poor during dry conditions as the process is transpiration driven (Gupta, 1985). The first study in Chapter two showed that B assimilation was greater than anticipated. Perhaps the lack of rainfall reduced the amount of B leached from the soil. However, the weather during the bloom period was favourable for pollination. Foliar-applied B has been noted to improve fruit set greater during cool, damp springs when overall set is poor compared with years when it is good (Hanson and Breen, 1985). Further study of environmental factors (i.e., rainfall, temperature) is needed to fully understand their role on B nutrition of the lowbush blueberry.

These studies have confirmed that foliar-applied B is a management practice that blueberry producers should use as a method of remediating low B levels in deficient fields and improving yields in already B sufficient fields. Foliar B applications have been shown to alleviate deficiencies more quickly than soil-applied. Boron applications were most successful when applied in the sprout year at tip dieback and in the crop year at bloom. Future studies should be continued to determine if these results are reproducible over time and at different locations.

The nature of B movement in the lowbush blueberry has not been determined. The use of radio-labelled B studies is recommended and should be conducted at different stages in the plant's development to determine if mobility is growth stage dependant. Split-applications were most successful in increasing yield in this study and should be evaluated further. Determining a suitable application method for producers is necessary as mixed results have been noted. The use of a boom sprayer is not practical as there is excessive tracking resulting

in yield reduction. Mist blowers have been ineffective in some instances as the pumps tend to pulsate and there are alternating strips that received either excess or minimal amounts of B. Finally future investigation of nutrient interactions with B are necessary to truly understand the significance of further applications of nutrients.

Appendices

Appendix 2.1. Soil B level in plots following treatments (May 20) of foliar-applied and soil-applied boron at the Nova Scotia Wild Blueberry Institute, Debert, NS.

		Soil B concentration ($g \cdot kg^{-1}$)					
Treatment		May 20	May 21	May 23	May 27	June 4	June 20
-Soil	-Foliar	0.18	0.15	0.23	0.15	0.15	0.18
-Soil	+Foliar	0.20	0.13	0.43	0.18	0.18	0.18
+Soil	-Foliar	0.18	0.18	0.53	0.43	0.70	0.53
+Soil	+Foliar	0.20	0.20	0.50	0.28	0.55	0.43
ANOVA Results [z]		NS	NS	S**	NS	S***	S**

[z] Factors were either non-significant or significant (*, **, ***) at P< (0.05, 0.01, and 0.001).

Appendix 2.2. Tissue B level in lowbush blueberry leaves in plots following treatments (May 20) of foliar-applied and soil-applied B at the Nova Scotia Wild Blueberry Institute, Debert, NS.

		Tissue B concentration ($\mu g \cdot g^{-1}$)					
Treatment		May 20	May 21	May 23	May 27	June 4	June 20
-Soil	-Foliar	17.0	17.4	20.1	17.4	18.3	20.5
-Soil	+Foliar	16.9	24.2	24.3	21.9	22.1	24.8
+Soil	-Foliar	17.6	17.7	20.2	32.0	73.6	114.0
+Soil	+Foliar	16.8	23.5	24.7	29.6	75.4	132.3
ANOVA Results [z]		NS	NS	NS	S***	S***	S***

[z] Factors were either non-significant or significant (*, **, ***) at P< (0.05, 0.01, and 0.001).

Appendix 2.3. Analysis of variance (ANOVA) results for repeated measures analysis of soil B levels at the N.S.W.B.I., Debert, NS.

Source [z]	May 20	May 21	May 23	May 27	June 4	June 20
Model	0.5885	0.3829	**0.0180**	0.1827	**0.0019**	**0.0153**
Soil	1.0000	0.1284	**0.0023**	0.0603	**0.0002**	**0.0023**
Foliar	0.1827	1.0000	1.0000	0.5026	0.4999	0.5322
S×F	1.0000	0.4301	0.7325	0.3523	0.3494	0.5322
R^2	0.1429	0.2174	0.5545	0.3225	0.6995	0.5671
Mean	0.1875	0.1625	0.3750	0.2563	0.3938	0.3250

[z] Factors which are considered significant P< 0.05 are indicated by bold typeface.

Appendix 2.4. Analysis of variance (ANOVA) results for repeated measures analysis of tissue B levels at the N.S.W.B.I., Debert, NS.

Source [z]	May 20	May 21	May 23	May 27	June 4	June 20
Model	0.8959	0.1118	0.1126	**0.0005**	**0.0001**	**0.0001**
Soil	0.9324	0.9217	0.4387	**0.0001**	**0.0001**	**0.0001**
Foliar	0.4635	**0.0202**[y]	**0.0241**[y]	0.6740	0.3388	0.4473
S×F	0.9576	0.7370	0.9166	0.1372	0.2453	0.6069
R^2	0.0558	0.4364	0.4355	0.8184	0.9508	0.9412
Mean	17.08	20.70	22.33	25.23	47.35	72.90

[z] Factors which are considered significant P< 0.05 are indicated by bold typeface.

Appendix 2.5. Analysis of variance (ANOVA) results for profile analysis of repeated measures soil B levels at the N.S.W.B.I., Debert, NS.

	P-value for F-statistic				
Source [z]	1 and 2[y]	2 and 3	3 and 4	4 and 5	5 and 6
Mean	0.2299	**0.0001**	0.0983	0.0670	0.3306
Soil	0.2299	**0.0049**	0.5214	0.0670	0.2539
Foliar	0.5390	1.0000	0.6456	1.0000	0.9281
S×F	0.5390	0.4590	0.6456	1.0000	0.7868

[z] Factors which are considered significant P< 0.05 are indicated by bold typeface.

[y] Profile analysis determines whether consecutive samples are different from one another. In this case samples 1, 2, 3, 4, 5, and 6 correspond with the following dates May 20, May 21, May 23, May 27, June 4, and June 20, respectively.

Appendix 2.6. Analysis of variance (ANOVA) results for contrast analysis of repeated measures soil B levels at the N.S.W.B.I., Debert, NS.

	P-value for F-statistic				
Source [z]	1 and 2[y]	1 and 3	1 and 4	1 and 5	1 and 6
Mean	0.2299	**0.0002**	0.1996	**0.0005**	**0.0097**
Soil	0.2299	**0.0025**	0.0889	**0.0002**	**0.0058**
Foliar	0.5390	0.7350	0.4046	0.3402	0.4187
S×F	0.5390	0.7350	0.4046	0.3402	0.5869

[z] Factors which are considered significant P< 0.05 are indicated by bold typeface.

[y] Contrast analysis determines whether samples are different from one particular sample point. In this case samples 1, 2, 3, 4, 5, and 6 correspond with the following dates May 20, May 21, May 23, May 27, June 4, and June 20, respectively.

Appendix 2.7. Analysis of variance (ANOVA) results for profile analysis of repeated measures of tissue B levels at the N.S.W.B.I., Debert, NS.

	P-value for F-statistic				
Source [z]	1 and 2[y]	2 and 3	3 and 4	4 and 5	5 and 6
Mean	**0.0032**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Soil	0.8617	0.4295	**0.0001**	**0.0001**	**0.0001**
Foliar	**0.0033**	**0.0048**	0.1645	0.2362	0.2676
S×F	0.7126	0.8685	0.0834	0.3997	0.6521

[z] Factors which are considered significant P< 0.05 are indicated by bold typeface.

[y] Profile analysis determines whether consecutive samples are different from one another. In this case samples 1, 2, 3, 4, 5, and 6 correspond with the following dates May 20, May 21, May 23, May 27, June 4, and June 20, respectively.

Appendix 2.8. Analysis of variance (ANOVA) results for contrast analysis of repeated measures tissue B levels at the N.S.W.B.I., Debert, NS.

	P-value for F-statistic				
Source	1 and 2	1 and 3	1 and 4	1 and 5	1 and 6
Mean	**0.0032**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Soil	0.8617	0.4295	**0.0001**	**0.0001**	**0.0001**
Foliar	**0.0033**	**0.0048**	0.1645	0.2362	0.2676
S×F	0.7126	0.8685	0.0834	0.3997	0.6521

[z] Factors which are considered significant P< 0.05 are indicated by bold typeface.

[y] Contrast analysis determines whether samples are different from one particular sample point. In this case samples 1, 2, 3, 4, 5, and 6 correspond with the following dates May 20, May 21, May 23, May 27, June 4, and June 20, respectively.

Appendix 2.9. Analysis of variance (ANOVA) results for yield at the N.S.W.B.I., Debert, NS

	P-value for F-statistic
Source	Yield
Model	0.0725
Soil	**0.0185**
Foliar	0.9321
S×F	0.2305
R^2	0.4289
Mean	537.84

[z] Factors which are considered significant P< 0.05 are indicated by bold typeface.

Appendix 2.10. Analysis of variance (ANOVA) results using the collapsed model for yield at the N.S.W.B.I., Debert, NS

	P-value for F-statistic
Source	Yield
Model	**0.0114**
Soil	**0.0114**
R^2	0.4003
Mean	537.84

[z] Factors which are considered significant P< 0.05 are indicated by bold typeface.

Appendix 2.11. Results of means separation for yield using Duncan's multiple range test at Debert, N.S.

Soil Level	Mean	Duncan Grouping [z]	Critical range
-Soil	593.20	a	88.63
+Soil	482.48	b	

[z] Means with the same letters are not significantly different from each other.

Appendix 2.12. Analysis of variance results for blueberry leaf nutrient levels sampled following application at Benvie Hill during the sprout (1997) and crop (1998) phases of production.

	P-value for F-statistic		
Source [z]	SY	BC	FC
Model	0.1852	0.3319	**0.0009**
Block	0.1405	0.1746	**0.0149**
SY	0.5143	0.3336	0.3985
BC		0.4986	**0.0451**
SY×BC		0.5978	0.1005
FC			**0.0001**
SY×FC			0.7466
BC×FC			0.3901
SY×BC×FC			0.0932
R^2	0.8087	0.4721	0.7205
Mean	35.60	25.28	34.12

[z] Factors which are considered significant P< 0.05 are indicated by bold typeface.

[y] Main effects and interactions cannot be considered significant if the overall model is non-significant.

Appendix 2.13. Analysis of variance results using the collapsed model for blueberry leaf nutrient levels sampled following application at fruit set at Benvie Hill during the crop (1998) phase of production.

	P-value for F-statistic
	FC
Source [z]	
Model	**0.0001**
Block	**0.0037**
BC	**0.0482**
FC	**0.0001**
BC×FC	0.5322
R^2	0.5776
Mean	34.12

[z] Factors which are considered significant P< 0.05 or marginally significant P< 0.10 are indicated by bold typeface.

Appendix 2.14. Results of means separation for B leaf levels sampled at fruit set caused by the main effect of application at BC using Duncan's multiple range test at Benvie Hill, N.S.

Treatment			
BC	Mean	Duncan rating [z]	Critical range
-	31.91	a	4.374
+	36.49	b	

[z] Means with the same letters are not significantly different from each other.

Appendix 2.15. Results of means separation for B leaf levels sampled at fruit set caused by the main effect of application at FC using Duncan's multiple range test at Benvie Hill, N.S.

Treatment			
FC	Mean	Duncan rating [z]	Critical range
-	26.68	a	4.374
+	39.23	b	

[z] Means with the same letters are not significantly different from each other.

Appendix 2.16. Analysis of variance results for blueberry leaf nutrient levels sampled following at Wood Islands during the sprout (1997) and crop (1998) phases of production.

	P-value for F-statistic		
	SY	BC	FC
Source [z]			
Model	0.6745	0.1280	**0.0007**
Block	0.6513	0.0629	**0.0073**
SY	0.4686	0.4180	0.5269
BC		0.2975	**0.0476**
SY×BC		0.2917	0.9350
FC			**0.0001**
SY×FC			0.7385
BC×FC			0.4186
SY×BC×FC			0.1828
R^2	0.4568	0.6034	0.7118
Mean	26.27	27.02	31.07

[z] Factors which are considered significant $P< 0.05$ are indicated by bold typeface.

Appendix 2.17. Analysis of variance results using the collapsed model for blueberry leaf nutrient levels sampled following application at fruit set at Wood Islands during the crop (1998) phase of production.

	P-value for F-statistic
	FC
Source [z]	
Model	**0.0007**
Block	0.1693
BC	**0.0815**
FC	**0.0001**
BC×FC	0.4840
R^2	0.4992
Mean	31.069

[z] Factors which are considered significant P< 0.05 or marginally significant P< 0.10 are indicated by bold typeface.

[y] Main effects and interactions can not be considered significant if the overall model is non-significant.

Appendix 2.18. Results of means separation for B leaf levels sampled at fruit set caused by the main effect of application at BC using Duncan's multiple range test at Wood Islands, P.E.I.

Treatment			
FC	Mean	Duncan rating [z]	Critical range
-	29.48	a	3.151
+	32.66	b	

[z] Means with the same letters are not significantly different from each other.

Appendix 2.19. Results of means separation for B leaf levels sampled at fruit set caused by the main effect of application at FC using Duncan's multiple range test at Wood Islands, N.S.

Treatment			
FC	Mean	Duncan rating [z]	Critical range
-	27.02	a	3.151
+	35.12	b	

[z] Means with the same letters are not significantly different from each other.

Table 2.20. Analysis of variance results for blueberry flower bud B levels sampled Wood Islands and Benvie Hill prior to bud break of the crop phase of production after application at SY.

	P-value for F-statistic		
	Bud B level		
Source [z]	Benvie Hill	Wood Islands	Combined
Model	0.2268	0.1740	**0.0198**
Block	0.1653	0.1491	**0.0167**
SY	1.0000	0.2630	0.1867
R^2	0.7779	0.8172	0.8915
Mean	21.78	17.55	19.50

[z] Factors which are considered significant $P < 0.05$ are indicated by bold typeface.

Appendix 2.21. Analysis of variance results for yield components sampled following bud break at Benvie Hill and Wood Islands (combined) for the 1998 growing season.

	P-value for F-statistic			
Source [z]	Stem length (cm)	Inflorescences	Flowers	Flowers per inflorescence
Model	0.7153	0.2340	**0.0049**	**0.0004**
Block	0.6803	0.1902	**0.0036**	**0.0003**
SY	0.5356	0.7385	0.5447	0.2920
R^2	0.4294	0.6687	0.9088	0.9585
Mean	18.12	6.80	30.76	4.52

[z] Factors which are considered significant P< 0.05 are indicated by bold typeface.

Appendix 2.22. Analysis of variance results for yield components sampled following fruit set at Benvie Hill and Wood Islands (combined) for the 1998 growing season.

	P-value for F-statistic					
Source [z]	Stem length (cm)	Node number per stem	Flowering node number per stem	Floral zone length (cm)	Flower number per stem	Fruit set per stem
Model	**0.0001**	**0.0466**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
Block	**0.0001**	**0.0134**	**0.0001**	**0.0001**	**0.0001**	**0.0001**
SY	0.7626	0.3620	0.9906	0.4673	0.9861	0.6519
BC	**0.0145**	0.5006	0.4606	0.7707	0.7032	0.5706
SY×BC	0.7125	0.2375	0.3510	0.2805	0.4828	0.5061
FC	0.4046	0.9052	0.5031	**0.0632**	0.6324	0.8580
SY×FC	0.2673	0.1273	0.3894	0.1148	0.3659	0.3048
BC×FC	0.2356	0.3208	**0.0195**	0.7790	0.1220	**0.0826**
SY×BC×FC	0.8744	0.4290	0.4453	0.2797	0.3300	0.3379
R^2	0.6225	0.3548	0.6843	0.8216	0.6658	0.6861
Mean	17.49	20.19	5.52	7.09	20.84	19.12

[z] Factors which are considered significant (P< 0.05) or marginally significant (0.05 <P>0.10) are indicated by bold typeface.

Appendix 2.23. Analysis of variance results of collapsed models for yield components sampled following fruit set at Benvie Hill and Wood Islands (combined) for the 1998 growing season.

	P-value for F-statistic			
Source [z]	Stem length (cm)	Flowering node number	Floral zone length (cm)	Fruit set
Model	**0.0001**	**0.0001**	0.0001	**0.0001**
Block	**0.0001**	**0.0001**	0.0001	**0.0001**
SY	-	-	-	-
BC	**0.0122**	0.4527	-	0.5726
SY×BC	-	-	-	-
FC	-	0.4956	0.0330	0.8561
SY×FC	-	-	-	-
BC×FC	-	**0.0173**	-	**0.0784**
SY×BC×FC	-	-	-	-
R^2	0.5943	0.6699	0.8386	0.6690
Mean	17.49	5.51	7.09	19.12

[z] Factors which are considered significant ($P< 0.05$) or marginally significant ($0.05 <P>0.10$) are indicated by bold typeface.

Appendix 2.24. Results of means separation using Duncan's multiple range test for stem length for the combined analysis at Benvie Hill, N.S. and Wood Islands, P.E.I. in 1998.

Treatments			
BC	Stem length (cm)	Duncan rating [z]	Critical range
-	17.99	a	1.078
+	16.99	b	

[z] Means with the same letters are not significantly different from each other.

Appendix 2.25. Results of means separation using LSMeans test for flowering node number for combined analysis at Benvie Hill, N.S. and Wood Islands, P.E.I.

Treatments		
BC	FC	Flowering Node Number
-	-	5.68 ab
-	+	5.13 b
+	-	5.15 b
+	+	6.12 a

[z] Means with the same letters are not significantly different from each other.

Appendix 2.26. Results of means separation using Duncan's multiple range test for floral zone length for the combined analysis at Benvie Hill, N.S. and Wood Islands, P.E.I. in 1998.

Treatments			
BC	Floral zone length (cm)	Duncan rating [z]	Critical range
-	6.32	a	1.393
+	7.85	b	

[z] Means with the same letters are not significantly different from each other.

Appendix 2.27. Results of means separation using Duncan's multiple range test for fruit set for the combined analysis at Benvie Hill, N.S. and Wood Islands, P.E.I. in 1998.

Treatments		
BC	FC	Fruit set per stem
-	-	19.73a
-	+	17.86a
+	-	18.30a
+	+	20.59a

[z] Means with the same letters are not significantly different from each other.

Appendix 2.28. Analysis of variance (ANOVA) results of dry matter accumulation sampled following fruit set at Benvie Hill and Wood Islands (combined) for the 1998 growing season.

	P-value for F-statistic		
Source	Fresh weight	Dry weight	% Dry matter
Model	**0.0001**	**0.0001**	**0.0001**
Block	**0.0001**	**0.0001**	**0.0001**
SY	0.6572	0.4303	0.3161
BC	0.2711	0.0811	0.4512
SY×BC	0.8015	0.6272	**0.0590**
FC	**0.0347**	**0.0383**	0.3374
SY×FC	0.9556	0.5702	0.3240
BC×FC	0.9129	0.4695	0.5068
SY×BC×FC	0.8763	0.8821	0.6177
R^2	0.8085	0.7620	0.6211
Mean	54.48	18.40	35.33

[z] Factors which are considered significant ($P < 0.05$) or marginally significant ($0.05 < P > 0.10$) are indicated by bold typeface.

Appendix 2.29. Analysis of variance (ANOVA) results using the collapsed models for dry matter accumulation sampled following fruit set at Benvie Hill and Wood Islands (combined) for the 1998 growing season.

	P-value for F-statistic		
Source	Fresh weight	Dry weight	% Dry matter
Model	**0.0001**	**0.0001**	**0.0001**
Block	**0.0001**	**0.0001**	**0.0001**
SY	-	-	0.3095
BC	-	-	0.4450
SY×BC	-	-	**0.0554**
FC	**0.0274**	**0.0360**	-
SY×FC	-	-	-
BC×FC	-	-	-
SY×BC×FC	-	-	-
R^2	0.8024	0.7381	0.6007
Mean	54.48	18.40	35.33

[z] Factors which are considered significant (P< 0.05) or marginally significant (0.05 <P>0.10) are indicated by bold typeface.

Appendix 2.30. Results of means separation using Duncan's multiple range test for fresh weight for the combined analysis at Benvie Hill, N.S. and Wood Islands, P.E.I. in 1998.

Treatments			
FC	Fresh weight (g)	Duncan rating [z]	Critical range
-	51.71	a	5.124
+	57.25	b	

[z] Means with the same letters are not significantly different from each other.

Appendix 2.31. Results of means separation using Duncan's multiple range test for dry weight for the combined analysis at Benvie Hill, N.S. and Wood Islands, P.E.I. in 1998.

Treatments			
FC	Dry weight (g)	Duncan rating [z]	Critical range
-	17.59	a	1.516
+	19.20	b	

[z] Means with the same letters are not significantly different from each other.

Appendix 2.32. Results of means separation using LSMeans test for dry matter percentage for the combined analysis at Benvie Hill, N.S. and Wood Islands, P.E.I. in 1998.

Treatments		
BC	FC	Dry matter [z] (%)
-	-	37.27 a
-	+	34.45 ab
+	-	34.18 b
+	+	35.41 ab

[z] Means with the same letters are not significantly different from each other.

Appendix 2.33. Analysis of variance results for lowbush blueberry yield at Benvie Hill and Wood Islands for the 1998 growing season.

	P-value for F-statistic			
	Yield			Berry Weight
Source [z]	Benvie Hill	Wood Islands	Combined	Combined
Model	0.2411	**0.0485**	**0.0029**	**0.0001**
Block	**0.0405**	**0.0096**	**0.0009**	**0.0001**
SY	0.5756	0.9695	0.6824	0.2684
BC	0.7916	0.7697	0.6790	0.7727
SY×BC	0.2588	0.6514	0.2283	0.4143
FC	0.7622	0.3499	0.6623	0.7229
SY×FC	0.1998	0.3757	0.1030	0.2101
BC×FC	0.7153	0.1169	0.1557	0.7260
SY×BC×FC	0.4760	**0.0617**	**0.0562**	0.8713
R^2	0.4023	0.5268	0.4539	0.6593
Mean	747.62	679.65	713.63	0.3476

[z] Factors which are considered significant (P< 0.05) or marginally significant (0.05 <P>0.10) are indicated by bold typeface.

Appendix 2.34. Results of means separation for yield using LSMeans test for Wood Islands, P.E.I. and the combined analysis (Benvie Hill, N.S. and Wood Islands P.E.I.) in 1998.

Treatment			Yield	
SY	BC	FC	Combined [z]	Wood Islands
-	-	-	723.1 ab	710.2 ab
-	-	+	748.9 ab	690.1 ab
-	+	-	644.6 b	653.8 ab
-	+	+	707.9 ab	668.6 ab
+	-	-	682.8 b	629.4 ab
+	-	+	730.1 ab	719.6 ab
+	+	-	836.1 a	823.9 a
+	+	+	635.5 b	541.7 b

[z] Means with the same letters are not significantly different from each other.

Appendix 3.1. Orthogonal treatment combinations of foliar-applied B, Ca, and Mg as specified by the three factor rotatable central composite design.

	Foliar nutrient concentration					
	B		Ca		Mg	
Treatment	Coded value	Concentration (ppm)	Coded value	Concentration (ppm)	Coded value	Concentration (ppm)
1	-1	142	-1	1622	-1	405
2	+1	558	-1	1622	-1	405
3	-1	142	+1	6378	-1	405
4	+1	558	+1	6378	-1	405
5	-1	142	-1	1622	+1	1595
6	+1	558	-1	1622	+1	1595
7	-1	142	+1	6378	+1	1595
8	+1	558	+1	6378	+1	1595
9	-1.682	0	0	4000	0	1000
10	+1.682	700	0	4000	0	1000
11	0	350	-1.682	0	-1.682	0
12	0	350	+1.682	8000	+1.682	2000
13	0	350	0	4000	0	1000
14	0	350	0	4000	0	1000
15	0	350	0	4000	0	1000
16	0	350	0	4000	0	1000

Appendix 3.2. Analysis of variance for phosphorus sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.000051	0.717	0.6897
Linear	3	0.000055	0.774	0.5160
Square	3	0.000063	0.876	0.4621
Interaction	3	0.000036	0.503	0.6827
Residual Error	38	0.000072		
Lack-of-Fit	35	0.000071	1.583	0.4005
Pure Error	3	0.000072		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.3. Estimated regression coefficients for phosphorus sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.129501	0.003445	37.595	**<0.001**
B	0.001724	0.001322	1.304	0.200
Ca	0.001041	0.001322	0.788	0.436
Mg	-0.000042	0.001322	-0.032	0.975
B^2	0.001769	0.001605	1.102	0.277
Ca^2	-0.000977	0.001605	-0.609	0.546
Mg^2	0.000408	0.001605	0.254	0.801
B×Ca	-0.000017	0.001727	-0.010	0.992
B×Mg	0.001608	0.001727	0.931	0.358
Ca×Mg	0.001383	0.001727	0.801	0.428
R^2 = 14.5%				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.4. Analysis of variance for potassium sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean Square	F- ratio	P > F [z]
Regression	9	0.000867	0.52	0.850
Linear	3	0.001529	0.92	0.440
Square	3	0.000425	0.26	0.857
Interaction	3	0.000645	0.39	0.762
Residual Error	38	0.001622		
Lack-of-Fit	35	0.000328	0.18	0.970
Pure Error	3	0.001864		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.5. Estimated regression coefficients for potassium sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.506393	0.016593	30.519	**<0.001**
B	0.006978	0.006368	1.096	0.280
Ca	0.006808	0.006368	1.069	0.292
Mg	0.004115	0.006368	0.646	0.522
B^2	-0.001149	0.007732	-0.149	0.883
Ca^2	-0.004573	0.007732	-0.591	0.558
Mg^2	-0.005963	0.007732	-0.771	0.445
B×Ca	-0.004471	0.008321	-0.537	0.594
B×Mg	0.006154	0.008321	0.740	0.464
Ca×Mg	-0.004771	0.008321	-0.573	0.570
R^2 = 11.0%				

[z] Parameters components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.6. Analysis of variance for calcium sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	2	0.013022	3.77	**0.031**
Linear	1	0.024750	7.16	**0.010**
Square	1	0.001294	0.37	0.544
Residual Error	45	0.003455		
Lack-of-Fit	42	0.004292	1.26	0.295
Pure Error	3	0.003416		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.7. Estimated regression coefficients for calcium sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.610005	0.011830	51.565	**<0.001**
Ca	0.024578	0.009183	2.677	**0.010**
Ca^2	-0.005912	0.009659	-0.612	0.544
R^2 = 14.3%				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.8. Analysis of variance for magnesium sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.000351	0.508	0.8592
Linear	3	0.000550	0.797	0.5031
Square	3	0.000434	0.629	0.6009
Interaction	3	0.000068	0.099	0.9601
Residual Error	38	0.000710		
Lack-of-Fit	35	0.000449	1.582	0.4007
Pure Error	3	0.000690		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.9. Estimated regression coefficients for magnesium sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.1887	0.0107	17.62	**<0.001**
B	-0.0023	0.0041	-0.344	0.733
Ca	0.0018	0.0041	0.259	0.797
Mg	0.0103	0.0041	1.486	0.146
B^2	0.0163	0.0049	1.154	0.256
Ca^2	0.0045	0.0049	0.323	0.749
Mg^2	-0.0027	0.0049	-0.188	0.852
B×Ca	0.0058	0.0054	0.382	0.705
B×Mg	-0.0055	0.0054	-0.360	0.721
Ca×Mg	0.0023	0.0054	0.148	0.883

R^2 = 10.8%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.10. Analysis of variance for boron sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	88.81	3.75	**0.002**
Linear	3	208.59	8.80	**0.000**
Square	3	22.00	0.93	0.437
Interaction	3	35.85	1.51	0.227
Residual Error	38	23.71		
Lack-of-Fit	35	24.04	1.02	0.424
Pure Error	3	23.66		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.11. Estimated regression coefficients for boron sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	32.7868	1.9821	16.541	**<0.001**
B	3.8803	0.7607	5.101	**<0.001**
Ca	0.4631	0.7607	0.609	0.546
Mg	-0.0518	0.7607	-0.068	0.946
B^2	1.2786	0.9237	1.384	0.174
Ca^2	0.8944	0.9237	0.968	0.339
Mg^2	1.3069	0.9237	1.415	0.165
B×Ca	-0.0533	0.9940	-0.054	0.957
B×Mg	1.1983	0.9940	1.206	0.235
Ca×Mg	1.7442	0.9940	1.755	**0.087**

R^2 = 47.0%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.12. Analysis of variance for copper sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.26229	2.48	**0.025**
Linear	3	0.23060	2.18	0.107
Square	3	0.34111	3.22	**0.033**
Interaction	3	0.21517	2.03	0.126
Residual Error	38	0.10592		
Lack-of-Fit	35	0.04847	0.42	0.829
Pure Error	3	0.11462		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.13. Estimated regression coefficients for copper sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	2.46079	0.13247	18.576	**<0.001**
B	0.03472	0.05084	0.683	0.499
Ca	0.12515	0.05084	2.461	**0.018**
Mg	-0.00417	0.05084	-0.082	0.935
B^2	0.11865	0.06173	1.922	**0.062**
Ca^2	0.16756	0.06173	2.714	**0.010**
Mg^2	0.01806	0.06173	0.293	0.771
B×Ca	0.06604	0.06643	0.994	0.326
B×Mg	0.13237	0.06643	1.993	**0.054**
Ca×Mg	0.07079	0.06643	1.066	0.293
R^2 = 37.0%				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.14. Analysis of variance for zinc sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	2.289	0.64	0.759
Linear	3	2.488	0.69	0.563
Square	3	2.139	0.59	0.623
Interaction	3	2.239	0.62	0.605
Residual Error	38	3.602		
Lack-of-Fit	35	1.441	0.37	0.868
Pure Error	3	3.929		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.15. Estimated regression coefficients for zinc sampled following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	7.8431	0.7725	10.153	**<0.001**
B	-0.1769	0.2965	-0.597	0.554
Ca	0.0638	0.2965	0.215	0.831
Mg	0.3832	0.2965	1.292	0.204
B^2	0.1592	0.3600	0.442	0.661
Ca^2	0.3933	0.3600	1.093	0.281
Mg^2	-0.0755	0.3600	-0.210	0.835
B×Ca	0.2507	0.3874	0.647	0.521
B×Mg	-0.3199	0.3874	-0.826	0.414
Ca×Mg	-0.3387	0.3874	-0.874	0.387

R^2 = 13.1%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.16. Analysis of variance for phosphorus sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean Square	F- ratio	P > F [z]
Regression	9	0.000118	0.91	0.530
Linear	3	0.000246	1.89	0.148
Square	3	0.000041	0.32	0.814
Interaction	3	0.000045	0.35	0.789
Residual Error	38	0.000130		
Lack-of-Fit	35	0.000055	0.38	0.855
Pure Error	3	0.000142		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.17. Estimated regression coefficients for phosphorus sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.158324	0.004638	34.133	**<0.001**
B	0.004134	0.001890	2.187	**0.035**
Ca	0.001515	0.001808	0.838	0.407
Mg	0.000384	0.001808	0.212	0.833
B^2	0.000832	0.002243	0.371	0.713
Ca^2	-0.001155	0.002171	-0.532	0.598
Mg^2	-0.001155	0.002171	-0.532	0.598
B×Ca	-0.001886	0.002388	-0.790	0.435
B×Mg	0.001447	0.002388	0.606	0.548
Ca×Mg	0.000220	0.002388	0.092	0.927

R^2 = 18.5%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.18 Analysis of variance for potassium sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.000437	0.31	0.31
Linear	3	0.000307	0.22	0.22
Square	3	0.000552	0.39	0.39
Interaction	3	0.000371	0.26	0.26
Residual Error	38	0.001417		
Lack-of-Fit	35	0.000577	0.37	0.37
Pure Error	3	0.001553		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.19. Estimated regression coefficients for potassium sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.495828	0.015326	32.352	**<0.001**
B	0.002828	0.006245	0.453	0.653
Ca	-0.003984	0.005974	-0.667	0.509
Mg	0.000609	0.005974	0.102	0.919
B^2	0.002505	0.007413	0.338	0.737
Ca^2	-0.005047	0.007174	-0.704	0.486
Mg^2	0.002024	0.007174	0.282	0.779
B×Ca	-0.005434	0.007889	-0.689	0.495
B×Mg	-0.004600	0.007889	-0.583	0.563
Ca×Mg	0.001267	0.007889	0.161	0.873

R^2 = 7.2%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.20. Analysis of variance for calcium sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.002068	0.87	0.559
Linear	3	0.002071	0.87	0.465
Square	3	0.001711	0.72	0.546
Interaction	3	0.002230	0.94	0.432
Residual Error	38	0.002376		
Lack-of-Fit	35	0.001399	0.55	0.736
Pure Error	3	0.002533		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.21. Estimated regression coefficients for calcium sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.452193	0.019844	22.788	**<0.001**
B	0.010542	0.008085	1.304	0.201
Ca	0.006747	0.007734	0.872	0.389
Mg	-0.002250	0.007734	-0.291	0.773
B^2	0.010810	0.009598	1.126	0.267
Ca^2	0.004032	0.009288	0.434	0.667
Mg^2	0.011692	0.009288	1.259	0.216
B×Ca	-0.004056	0.010214	-0.397	0.694
B×Mg	-0.004056	0.010214	-0.397	0.694
Ca×Mg	0.016556	0.010214	1.621	0.114

R^2 = 17.9%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.22. Analysis of variance for magnesium sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.003125	0.99	0.469
Linear	3	0.000234	0.15	0.927
Square	3	0.002178	2.11	0.115
Interaction	3	0.000713	0.67	0.573
Residual Error	38	0.012685		
Lack-of-Fit	35	0.000902	0.47	0.792
Pure Error	3	0.011783		
Total	47	0.015811		

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.23. Estimated regression coefficients for magnesium sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.153367	0.007642	20.068	**<0.001**
B	0.000194	0.003114	0.062	0.951
Ca	0.000831	0.002979	0.279	0.782
Mg	-0.001810	0.002979	-0.608	0.547
B^2	0.009310	0.003696	2.519	**0.016**
Ca^2	0.003455	0.003577	0.966	0.341
Mg^2	0.003455	0.003577	0.966	0.341
B×Ca	-0.000282	0.003934	-0.072	0.943
B×Mg	-0.004448	0.003934	-1.131	0.266
Ca×Mg	0.003615	0.003934	0.919	0.364

R^2 = 19.8%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.24. Analysis of variance for boron sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	26.4	3.26	**0.005**
Linear	3	35.055	4.33	**0.011**
Square	3	31.508	3.89	**0.017**
Interaction	3	6.311	0.78	0.513
Residual Error	38	8.101		
Lack-of-Fit	35	2.745	0.31	0.905
Pure Error	3	8.965		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.25. Estimated regression coefficients for boron sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	21.3254	1.1588	18.403	**<0.001**
B	1.6498	0.4721	3.494	**0.001**
Ca	-0.0475	0.4517	-0.105	0.917
Mg	-0.4487	0.4517	-0.993	0.327
B^2	1.7885	0.5605	3.191	**0.003**
Ca^2	1.1987	0.5424	2.210	**0.034**
Mg^2	1.1280	0.5424	2.080	**0.045**
B×Ca	-0.4045	0.5965	-0.678	0.502
B×Mg	-0.3128	0.5965	-0.524	0.603
Ca×Mg	0.7962	0.5965	1.335	0.190

R^2 = 44.9%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.26. Analysis of variance for copper sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	1.0943	0.56	0.820
Linear	3	0.2334	0.12	0.948
Square	3	1.6510	0.85	0.478
Interaction	3	1.2811	0.66	0.584
Residual Error	38	1.9521		
Lack-of-Fit	35	1.5297	0.76	0.587
Pure Error	3	2.0202		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.27. Estimated regression coefficients for copper sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	5.7069	0.5688	10.033	**<0.001**
B	0.1124	0.2318	0.485	0.631
Ca	0.0286	0.2217	0.129	0.898
Mg	0.0682	0.2217	0.308	0.760
B^2	0.0647	0.2751	-0.235	0.815
Ca^2	0.4085	0.2662	-1.534	0.134
Mg^2	0.1905	0.2662	-0.716	0.479
B×Ca	0.2168	0.2928	-0.740	0.464
B×Mg	0.1085	0.2928	-0.370	0.713
Ca×Mg	0.3501	0.2928	1.196	0.240
R^2 = 12.3%				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.28. Analysis of variance for zinc sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.001485	1.09	0.383
Linear	3	0.000322	0.68	0.512
Square	3	0.000066	0.13	0.880
Interaction	3	0.001097	4.01	**0.052**
Residual Error	38	0.010942		
Lack-of-Fit	35	0.000952	1.18	0.332
Pure Error	3	0.009990		
Total	47	0.012427		

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.29. Estimated regression coefficients for zinc sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998)at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T
Constant	0.581196	0.004595	126.496	**<0.001**
B	-0.002991	0.002737	-1.093	0.281
Ca	-0.000986	0.002619	-0.376	0.709
B^2	0.001156	0.003002	0.385	0.702
Ca^2	-0.000611	0.002851	-0.214	0.831
B×Ca	-0.006918	0.003455	-2.002	**0.052**

R^2 = 12.0%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.30. Analysis of variance (ANOVA) for winter damage to the terminal bud sampled in the early spring (1998) following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean Square	F- ratio	P > F [z]
Regression	2	0.146468	1.85	0.168
Linear	1	0.292935	3.71	**0.060**
Square	1	0.000000	0.00	0.998
Residual Error	45	0.078959		
Lack-of-Fit	42	0.072121	0.91	0.410
Pure Error	3	0.079277		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.31. Estimated regression coefficients for winter damage to the terminal bud sampled in the early spring (1998) following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	1.55007	0.05656	27.408	**<0.001**
B	0.08456	0.04390	1.926	**0.060**
B^2	0.00013	0.04618	0.003	0.998

R^2 = 7.6%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.32. Analysis of variance for winter damage to the vascular tissue at the terminal bud sampled in the early spring (1998) following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	2	0.183658	1.61	0.210
Linear	1	0.367310	3.23	**0.079**
Square	1	0.000005	0.00	0.995
Residual Error	45	0.113781		
Lack-of-Fit	42	0.129455	1.15	0.328
Pure Error	3	0.113052		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.33. Estimated regression coefficients for winter damage to the vascular tissue at the terminal bud sampled in the early spring (1998) following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.65242	0.06789	9.610	**<0.001**
Ca	-0.09468	0.05270	-1.797	**0.079**
Ca^2	0.00038	0.05543	0.007	0.995
$R^2 = 6.7\%$				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.34. Analysis of variance for winter damage to the fourth sampled in the early spring (1998) following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.12758	0.40	0.929
Linear	3	0.06765	0.63	0.599
Square	3	0.02698	0.25	0.860
Interaction	3	0.03295	0.31	0.820
Residual Error	38	1.35713		
Lack-of-Fit	35	0.04884	0.25	0.939
Pure Error	3	1.30829		
Total	47	1.48471		

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.35. Estimated regression coefficients for winter damage to the fourth sampled in the early spring (1998) following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	1.31924	0.07693	17.150	**<0.001**
B	0.01384	0.02952	0.469	0.642
Ca	-0.03250	0.02952	-1.101	0.278
Mg	0.02008	0.02952	0.680	0.501
B^2	-0.01581	0.03585	-0.441	0.662
Ca^2	-0.02708	0.03585	-0.755	0.455
Mg^2	-0.00004	0.03585	-0.001	0.999
B×Ca	-0.03302	0.03858	-0.856	0.397
B×Mg	-0.01681	0.03858	0.436	0.665
Ca×Mg	0.00017	0.03858	-0.004	0.997

$R^2 = 8.6\%$

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.36. Analysis of variance for bud number sampled in the early spring (1998) following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	1.4100	0.47	0.888
Linear	3	2.4149	0.80	0.502
Square	3	0.8033	0.27	0.850
Interaction	3	1.0119	0.33	0.800
Residual Error	38	3.0243		
Lack-of-Fit	35	0.8844	0.26	0.929
Pure Error	3	3.3485		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.37. Estimated regression coefficients for bud number sampled in the early spring (1998) following foliar applications of B, Ca, and Mg at tip dieback in the sprout phase of production (1997) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	6.8132	0.7079	9.625	**<0.001**
B	0.1643	0.2717	0.605	0.549
Ca	0.0905	0.2717	0.333	0.741
Mg	0.3764	0.2717	1.385	0.174
B^2	-0.2195	0.3299	-0.665	0.510
Ca^2	-0.2615	0.3299	-0.793	0.433
Mg^2	-0.1959	0.3299	-0.594	0.556
B×Ca	0.0507	0.3550	0.143	0.887
B×Mg	0.2701	0.3550	0.761	0.451
Ca×Mg	-0.2257	0.3550	-0.636	0.529

R^2 = 9.9%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.38. Analysis of variance for stem length at bud break (crop phase of production) as influenced by foliar applications of B, Ca, and Mg at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	3.4058	0.53	0.846
Linear	3	7.7982	1.27	0.300
Square	3	0.3307	0.08	0.968
Interaction	3	2.0804	0.23	0.876
Residual Error	38	7.4992		
Lack-of-Fit	35	9.9564	1.38	0.256
Pure Error	3	7.1269		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.39. Estimated regression coefficients for stem length at bud break (crop phase of production) as influenced by foliar applications of B, Ca, and Mg at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.001779	0.000193	9.234	**<0.001**
B	0.000075	0.000074	1.010	0.319
Ca	-0.000072	0.000074	-0.977	0.335
Mg	-0.000100	0.000074	-1.350	0.185
B^2	0.000015	0.000090	0.173	0.864
Ca^2	0.000033	0.000090	0.364	0.718
Mg^2	0.000041	0.000090	0.461	0.647
B×Ca	-0.000072	0.000097	-0.741	0.463
B×Mg	-0.000010	0.000097	-0.106	0.916
Ca×Mg	0.000034	0.000097	0.354	0.725

R^2 = 11.1%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.40. Analysis of variance for number of inflorescences at bud break (crop phase of production) as influenced by foliar applications of B, Ca, and Mg at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	5	16.540	1.60	0.181
Linear	2	2.128	0.21	0.815
Square	2	9.697	0.94	0.399
Interaction	1	59.049	5.72	**0.021**
Residual Error	42	10.331		
Lack-of-Fit	39	22.722	2.42	**0.080**
Pure Error	3	9.378		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.41. Estimated regression coefficients for number of inflorescences at bud break (crop phase of production) as influenced by foliar applications of B, Ca, and Mg at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	12.680	0.8905	14.240	**<0.001**
B	0.155	0.5022	0.309	0.759
Ca	-0.283	0.5022	-0.563	0.577
B^2	-0.712	0.5530	-1.288	0.205
Ca^2	0.036	0.5530	0.065	0.949
B×Ca	-1.569	0.6561	-2.391	**0.021**
R^2 = 16.0%				

[z] Parameters components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.42. Analysis of variance for number of flowers at bud break (crop phase of production) as influenced by foliar applications of B, Ca, and Mg at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean Square	F- ratio	P > F [z]
Regression	9	40.35	0.60	0.787
Linear	3	57.53	0.86	0.471
Square	3	15.14	0.23	0.878
Interaction	3	48.39	0.72	0.545
Residual Error	38	67.06		
Lack-of-Fit	35	58.60	0.86	0.520
Pure Error	3	68.35		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.43. Estimated regression coefficients for number of flowers per inflorescence at bud break (crop phase of production) as influenced by foliar applications of B, Ca, and Mg at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.158324	0.004638	34.133	**<0.001**
B	0.004134	0.001890	2.187	**0.035**
Ca	0.001515	0.001808	0.838	0.407
Mg	0.000384	0.001808	0.212	0.833
B^2	0.000832	0.002243	0.371	0.713
Ca^2	-0.001155	0.002171	-0.532	0.598
Mg^2	-0.001155	0.002171	-0.532	0.598
B×Ca	-0.001886	0.002388	-0.790	0.435
B×Mg	0.001447	0.002388	0.606	0.548
Ca×Mg	0.000220	0.002388	0.092	0.927

R^2 = 18.5%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.44. Analysis of variance for number of flowers per inflorescence at bud break (crop phase of production) as influenced by foliar applications of B, Ca, and Mg at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	2	1.39242	3.14	**0.053**
Linear	1	2.41865	5.46	**0.024**
Square	1	0.36619	0.83	0.368
Residual Error	45	0.44330		
Lack-of-Fit	42	0.06151	0.13	0.875
Pure Error	3	0.46105		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.45. Estimated regression coefficients for number of flowers per inflorescence at bud break (crop phase of production) as influenced by foliar applications of B, Ca, and Mg at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	5.06518	0.1340	37.799	**<0.001**
Ca	0.24297	0.1040	2.336	**0.024**
Ca^2	-0.09944	0.1094	-0.909	0.368
R^2 = 12.3%				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.46. Analysis of variance for number of nodes sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	5	1.1090×10^{11}	2.23	**0.069**
Linear	2	1.5359×10^{10}	0.31	0.736
Square	2	1.7385×10^{11}	3.49	**0.040**
Interaction	1	1.7609×10^{11}	3.54	**0.067**
Residual Error	42	4.9803×10^{11}		
Lack-of-Fit	39	1.1189×10^{11}	2.48	**0.075**
Pure Error	3	4.5027×10^{11}		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.47. Estimated regression coefficients for number of nodes sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	577752	61825	9.345	**<0.001**
Ca	15936	34865	0.457	0.650
Mg	-22267	34865	-0.639	0.527
Ca^2	-72146	38398	-1.879	**0.067**
Mg^2	46755	38398	1.218	0.230
Ca×Mg	-85658	45554	-1.880	**0.067**
$R^2 = 21.0\%$				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.48. Analysis of variance for number of flowering nodes sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.004069	0.46	0.894
Linear	3	0.002396	0.27	0.847
Square	3	0.006028	0.68	0.572
Interaction	3	0.003783	0.42	0.736
Residual Error	38	0.008905		
Lack-of-Fit	35	0.008529	0.95	0.461
Pure Error	3	0.008962		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.49. Estimated regression coefficients for number of flowering nodes sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	1.43995	0.036841	37.488	**<0.001**
B	0.00407	0.01474	0.276	0.784
Ca	-0.00755	0.01474	-0.512	0.612
Mg	0.01010	0.01474	0.685	0.498
B^2	-0.01421	0.01790	-0.794	0.432
Ca^2	-0.01903	0.01790	-1.063	0.294
Mg^2	0.00362	0.01790	0.202	0.841
B×Ca	-0.01381	0.01926	-0.717	0.478
B×Mg	0.00107	0.01926	0.055	0.956
Ca×Mg	0.01676	0.01926	0.870	0.390

R^2 = 9.8%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.50. Analysis of variance for stem length sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	4.0646	1.46	0.197
Linear	3	2.0908	0.75	0.528
Square	3	0.7538	0.27	0.846
Interaction	3	9.3492	3.36	**0.028**
Residual Error	38	2.7800		
Lack-of-Fit	35	1.8722	0.64	0.670
Pure Error	3	2.9176		
Total	47			

Appendix 3.51. Estimated regression coefficients for stem length sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	18.9234	0.6787	27.882	**<0.001**
B	-0.2810	0.2605	-1.079	0.288
Ca	0.2529	0.2605	0.971	0.338
Mg	-0.1010	0.2605	-0.388	0.700
B^2	-0.1934	0.3163	-0.612	0.544
Ca^2	-0.2529	0.3163	-0.800	0.429
Mg^2	-0.0538	0.3163	-0.170	0.866
B×Ca	0.6798	0.3403	1.997	**0.053**
B×Mg	-0.8044	0.3403	-2.363	**0.023**
Ca×Mg	-0.2440	0.3403	-0.717	0.478
$R^2 = 25.7\%$				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.52. Analysis of variance for floral zone length sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.7101	0.61	0.779
Linear	3	0.1493	0.13	0.942
Square	3	1.7481	1.51	0.228
Interaction	3	0.2329	0.20	0.895
Residual Error	38	1.1603		
Lack-of-Fit	35	1.0046	0.85	0.525
Pure Error	3	1.1839		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.53. Estimated regression coefficients for floral zone length sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	3.9804	0.4385	9.078	**<0.001**
B	-0.0141	0.1683	-0.084	0.934
Ca	-0.1030	0.1683	-0.612	0.544
Mg	-0.0116	0.1683	-0.069	0.945
B^2	-0.3168	0.2043	-1.551	0.129
Ca^2	-0.2429	0.2043	-1.189	0.242
Mg^2	0.0694	0.2043	0.340	0.736
B×Ca	-0.0679	0.2199	-0.309	0.759
B×Mg	-0.0092	0.2199	-0.042	0.967
Ca×Mg	0.1562	0.2199	0.711	0.482
R^2 = 12.7%				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.54. Analysis of variance for flower number sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.004069	0.46	0.894
Linear	3	0.002396	0.27	0.847
Square	3	0.006028	0.68	0.572
Interaction	3	0.003783	0.42	0.736
Residual Error	38	0.008905		
Lack-of-Fit	35	0.008529	0.95	0.461
Pure Error	3	0.008962		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.55. Estimated regression coefficients for flower number sampled following foliar applications of B, Ca, and Mg at bloom in the crop phase of production (1998) at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	1.43995	0.03841	37.488	**<0.001**
B	0.00407	0.01474	0.276	0.784
Ca	0.00755	0.01474	-0.512	0.612
Mg	0.01010	0.01474	0.685	0.498
B^2	0.01421	0.01790	-0.794	0.432
Ca^2	0.01903	0.01790	-1.063	0.294
Mg^2	0.00362	0.01790	0.202	0.841
B×Ca	0.01381	0.01926	-0.717	0.478
B×Mg	0.00107	0.01926	0.055	0.956
Ca×Mg	0.01676	0.01926	0.870	0.390

R^2 = 9.8%

[z] Parameters components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.56. Analysis of variance for yield of once-sprayed plots harvested August 20, 1998 at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	20158	0.77	0.648
Linear	3	15257	0.58	0.632
Square	3	14123	0.54	0.660
Interaction	3	31094	1.18	0.330
Residual Error	38	26324		
Lack-of-Fit	35	9659	0.33	0.888
Pure Error	3	28850		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.57. Estimated regression coefficients for yield of once-sprayed plots harvested August 20, 1998 at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	422.89	66.04	6.403	**<0.001**
B	27.14	25.35	1.071	0.291
Ca	3.19	25.35	0.126	0.900
Mg	19.25	25.35	0.750	0.452
B^2	-10.76	30.78	-0.350	0.729
Ca^2	-0.30	30.78	-0.010	0.992
Mg^2	28.99	30.78	0.942	0.352
B×Ca	-28.99	33.12	-0.875	0.387
B×Mg	-46.85	33.12	-1.415	0.165
Ca×Mg	29.17	33.12	0.881	0.384
R^2 = 15.4%				

[z] Parameters components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.58. Analysis of variance for yield of twice-sprayed plots harvested August 20, 1998 at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	5	67658	2.16	**0.077**
Linear	2	69780	2.23	0.120
Square	2	59753	1.91	0.161
Interaction	1	79224	2.53	0.119
Residual Error	42	31326		
Lack-of-Fit	39	44181	1.46	0.241
Pure Error	3	30337		
Total	47			

[z] Regression components which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.59. Estimated regression coefficients for yield of twice-sprayed plots harvested August 20, 1998 at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	374.57	49.03	7.639	**<0.001**
B	16.84	27.65	0.609	0.546
Mg	55.88	27.65	2.021	**0.050**
B^2	56.20	30.45	1.846	**0.072**
Mg^2	35.25	30.45	1.158	0.254
B×Mg	-57.45	36.13	-1.590	0.119
R^2 = 20.5%				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.60. Analysis of variance for berry weight of once-sprayed plots harvested August 20, 1998 at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	9	0.001674	0.49	0.873
Linear	3	0.000818	0.24	0.869
Square	3	0.001327	0.39	0.763
Interaction	3	0.002943	0.86	0.471
Residual Error	38	0.003428		
Lack-of-Fit	35	0.000471	0.12	0.987
Pure Error	3	0.003905		
Total	47			

Appendix 3.61. Estimated regression coefficients for berry weight of once-sprayed plots harvested August 20, 1998 at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.362365	0.026095	13.887	**<0.001**
B	0.003938	0.009290	0.424	0.674
Ca	0.001040	0.009290	0.112	0.912
Mg	0.006783	0.009290	0.730	0.470
B^2	-0.004151	0.011702	-0.355	0.725
Ca^2	-0.000984	0.011702	-0.084	0.933
Mg^2	0.008184	0.011702	0.699	0.489
B×Ca	-0.008514	0.012268	-0.694	0.492
B×Mg	-0.004022	0.012268	-0.328	0.745
Ca×Mg	0.016922	0.012268	1.379	0.176

R^2 = 10.9%

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

Appendix 3.62. Analysis of variance for berry weight of twice-sprayed plots harvested August 20, 1998 at Lynn Mountain, N.S.

Source	Degrees of freedom	Mean square	F- ratio	P > F [z]
Regression	2	0.008839	1.94	0.156
Linear	1	0.000571	0.13	0.725
Square	1	0.017082	3.75	**0.059**
Residual Error	45	0.004557		
Lack-of-Fit	42	0.002857	0.62	0.545
Pure Error	3	0.004638		
Total	47			

Appendix 3.63. Estimated regression coefficients for berry weight of twice-sprayed plots harvested August , 1998 at Lynn Mountain, N.S.

Term	Coded parameter estimate	Standard deviation	T for H0: Parameter = 0	P > T [z]
Constant	0.356708	0.01364	26.151	**<0.001**
B	-0.003782	0.01068	-0.354	0.725
B^2	0.021485	0.01110	1.936	**0.059**
$R^2 = 8.1\%$				

[z] Parameters which are considered significant (P< 0.10) are indicated by bold typeface.

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